



Daylighting Modeling and Analysis

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What we will talk about

today...

- Daylighting Basics
- Summary of Modeling Inputs
- Radiosity vs. Ray Tracing
- Summary of Modeling Outputs
- Daylighting Metrics
- Overview of Daylighting Tools
- Some Pretty Pictures
- Daylighting in SPOT, DAYSIM, and IES



Daylighting...what is it?

Table 1: Five sample definitions for daylighting (Reinhart C F & Galasiu A, 2006).

Architectural definition: the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment
Lighting Energy Savings definition: the replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting
Building Energy Consumption definition: the use of fenestration systems and responsive electric lighting controls to reduce overall building energy requirements (heating, cooling, lighting)
Load Management definition: dynamic control of fenestration and lighting to manage and control building peak electric demand and load shape
Cost definition: the use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity

Which of the following definitions for daylighting is the most relevant to you?

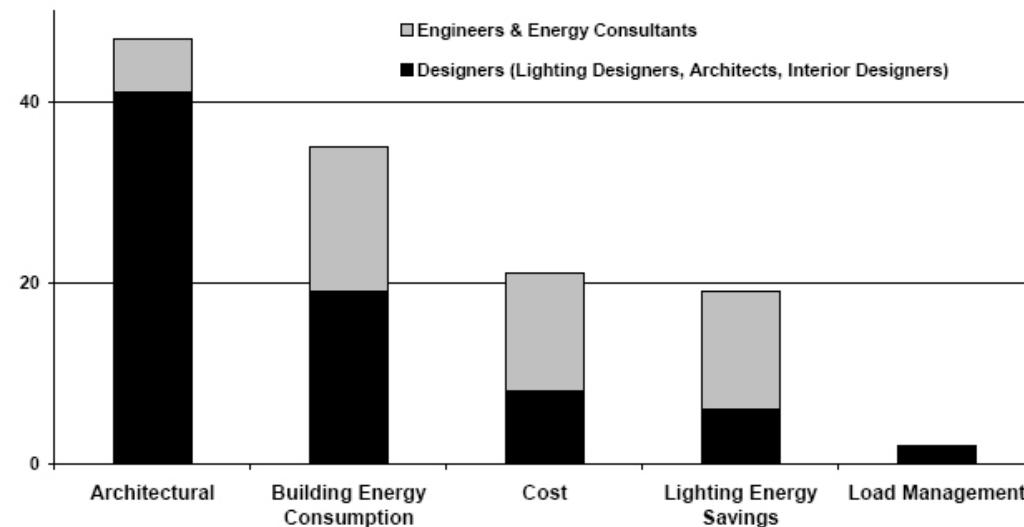


Figure 1: Results of a recent survey on the role of daylighting in sustainable design (Reinhart C F & Galasiu A, 2006).

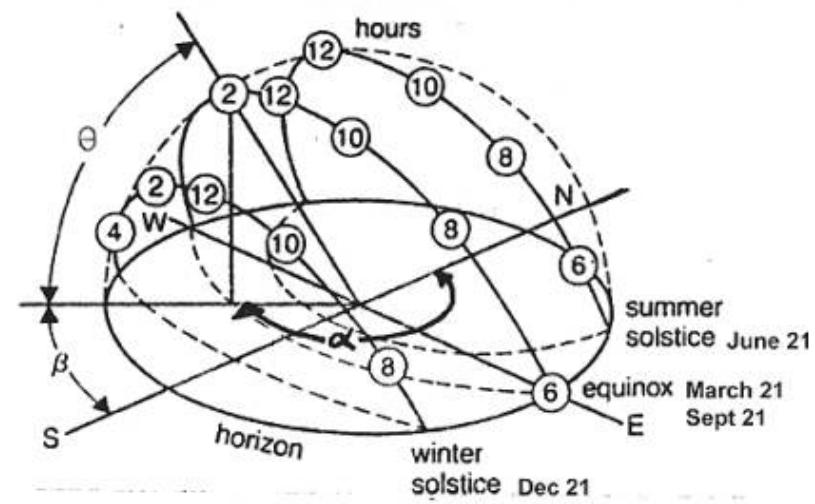
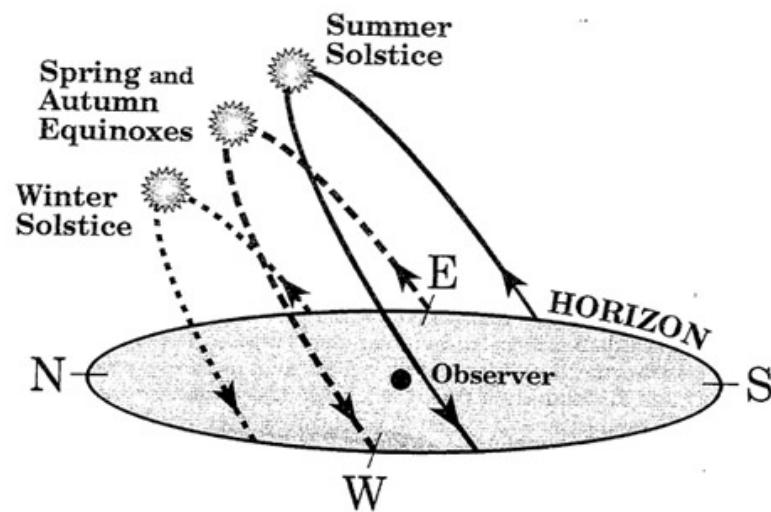


Daylighting...why do we care?

- Aesthetic value
- Health value
- Economic value
- Functional value
- Thermal value
- It's just plain cool

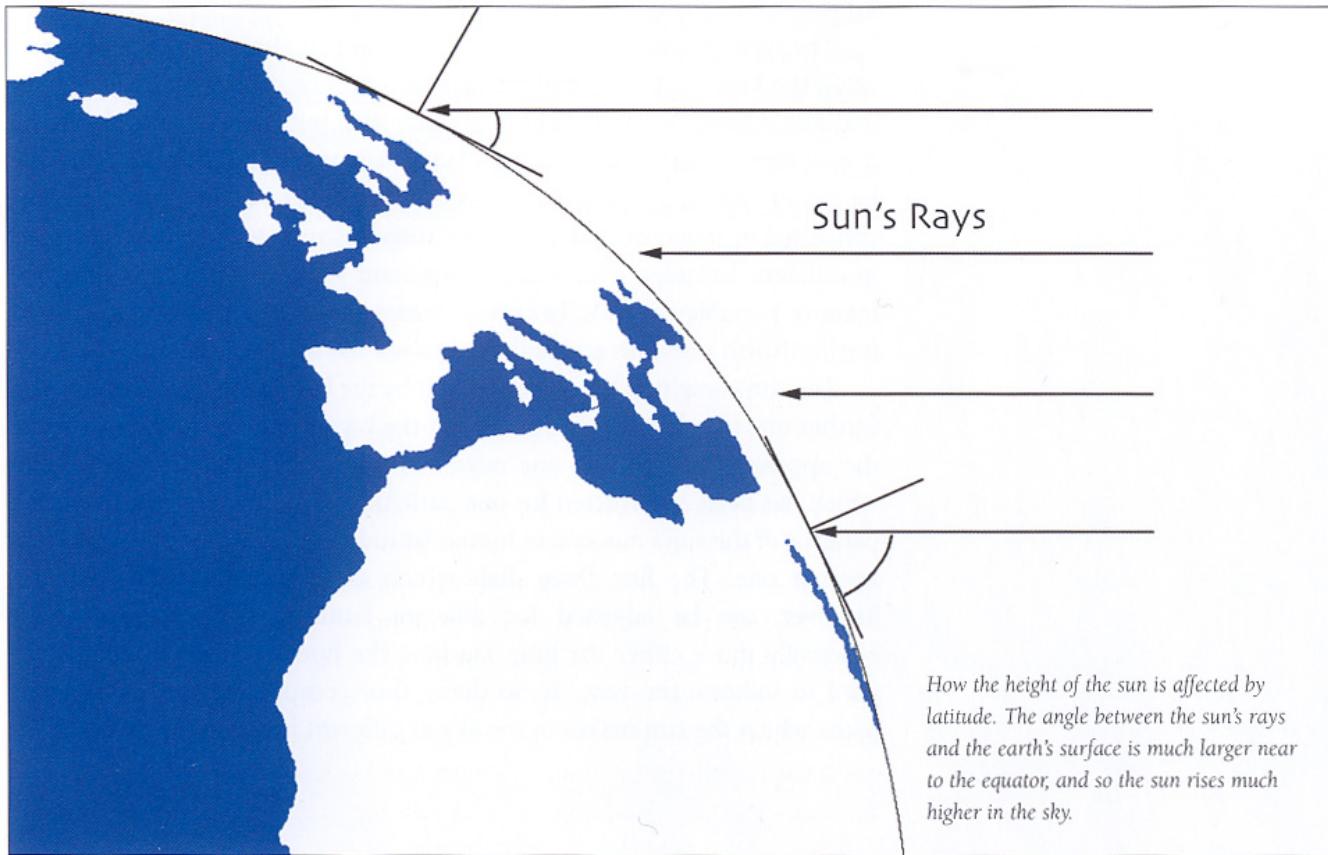


Solar Position



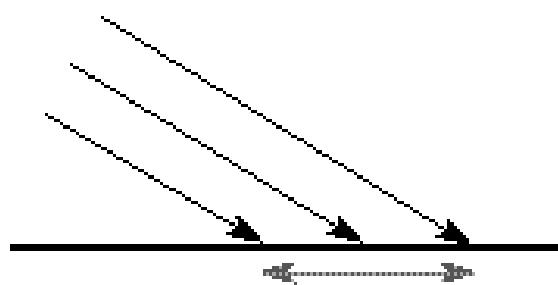


Variations in Incident Solar

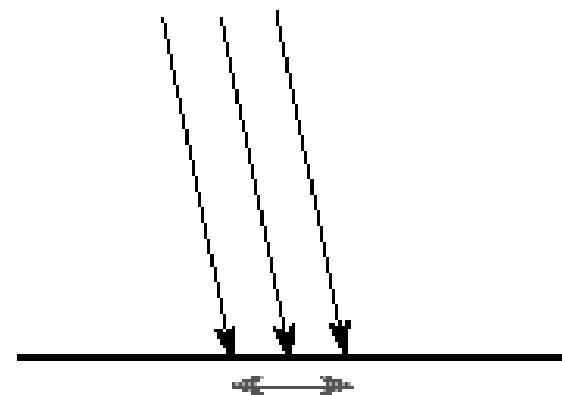




Seasonal Angles



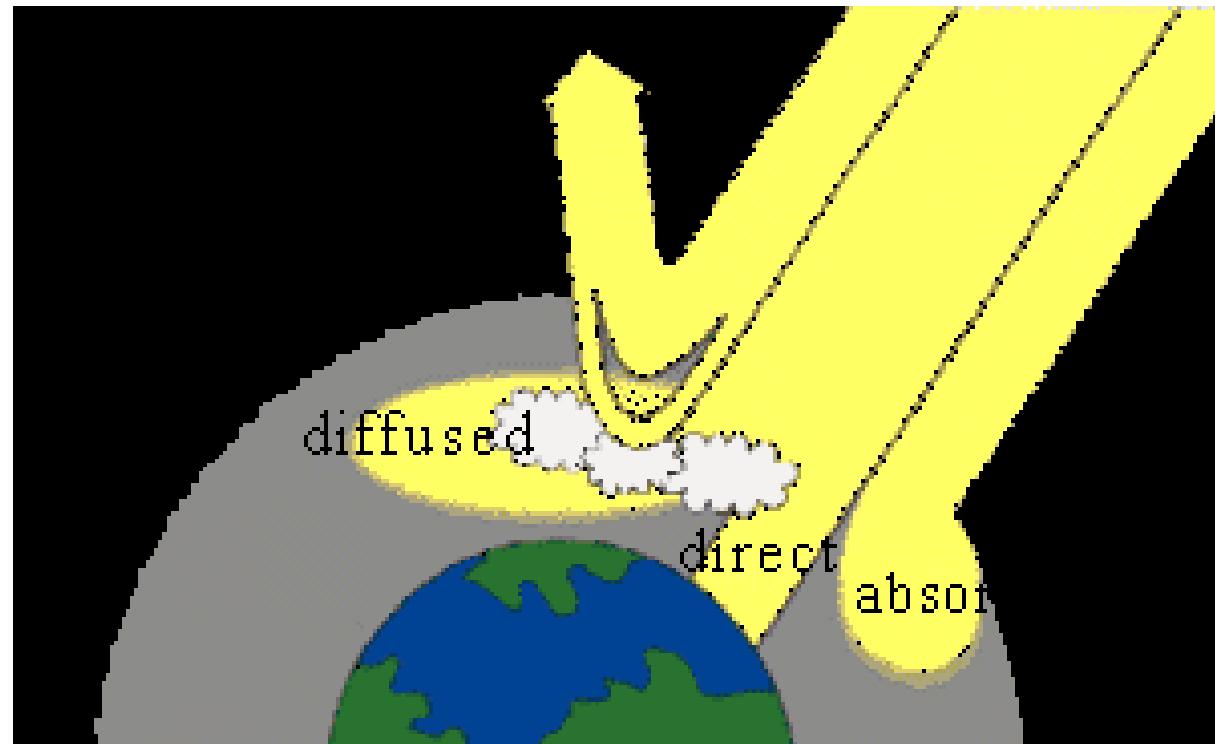
Same energy but more spread out, means less heating.



Same energy but more concentrated, means greater heating.



Diffuse and Direct Components





Diffuse Sky Conditions

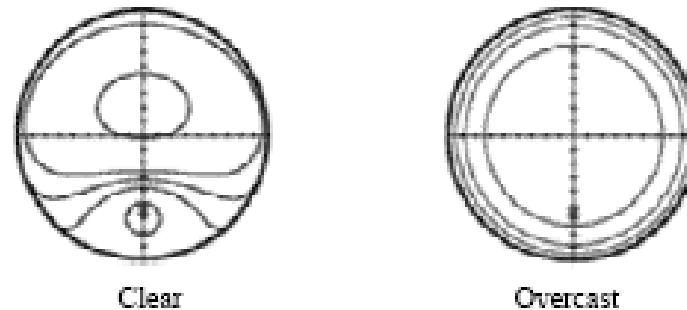
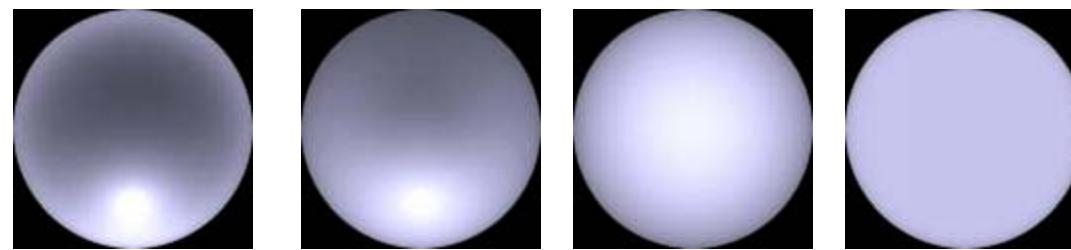


Fig. 1 CIE Sky Luminance Distribution Functions



Clear sky

Intermediate sky

Overcast sky

Uniform sky

LIGHTING/DAYLIGHTING ANALYSIS: A COMPARISON

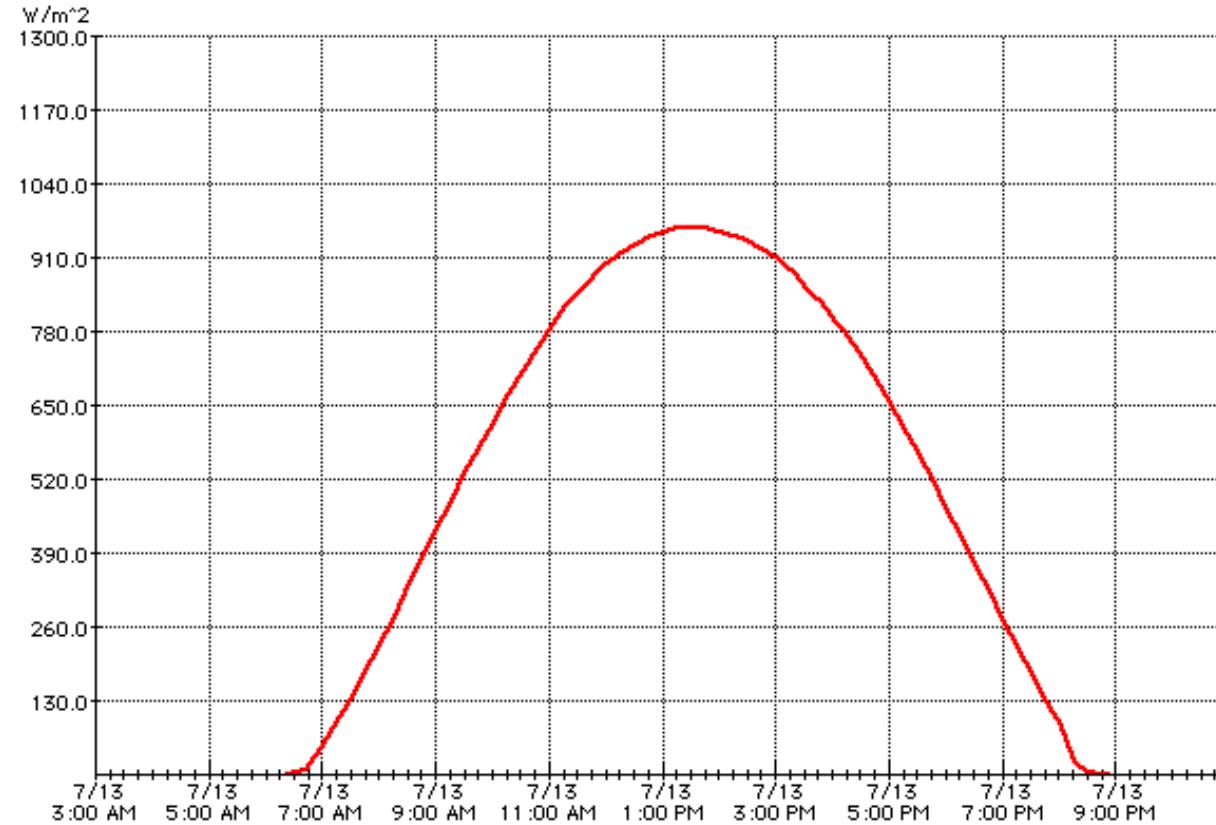
Harvey Bryan, Ph.D., FAIA

Sayyed Mohammed Autif

http://www.learn.londonmet.ac.uk/packages/clear/visual/daylight/sun_sky/sky_types.html



Daily Solar Radiation

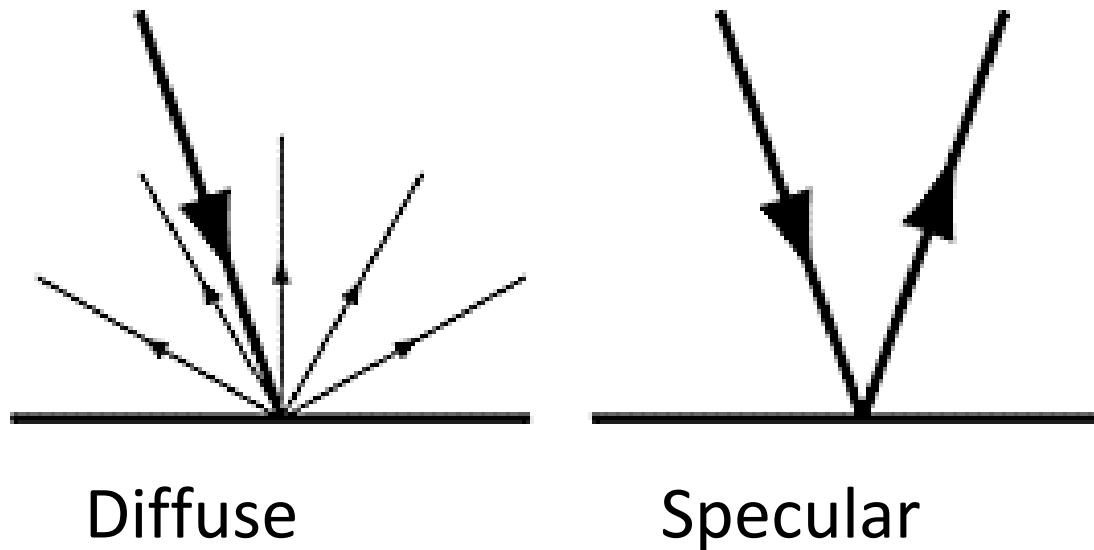


Time
Start: 7/13/97 03:00 AM (CDT)
End: 7/13/97 11:00 PM (CDT)
Interval: 0:15

Plots
✓ — Solar Radiation (W/m^2)
Spencer



Surface Properties





Glazing Types

Window Technologies: Glazing Types



Single-glazed Clear



Single-glazed with Bronze/Gray Tint



Double-glazed Clear



Double-glazed with Bronze/Gray Tint



Double-glazed with High Performance Tint



Double-glazed with High-Solar-Gain Low-E, Argon/Krypton Gas



Double-glazed with Moderate-Solar-Gain Low-E, Argon/Krypton Gas



Double-glazed with Low-Solar-Gain Low-E Argon/Krypton Gas



Triple-glazed with Moderate-Solar-Gain Low-E, Argon/Krypton Gas



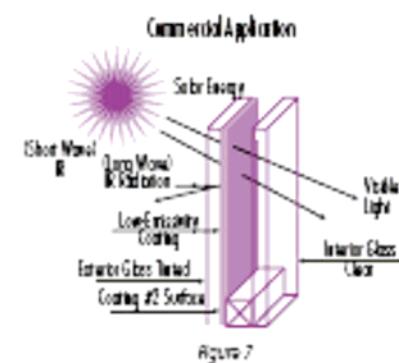
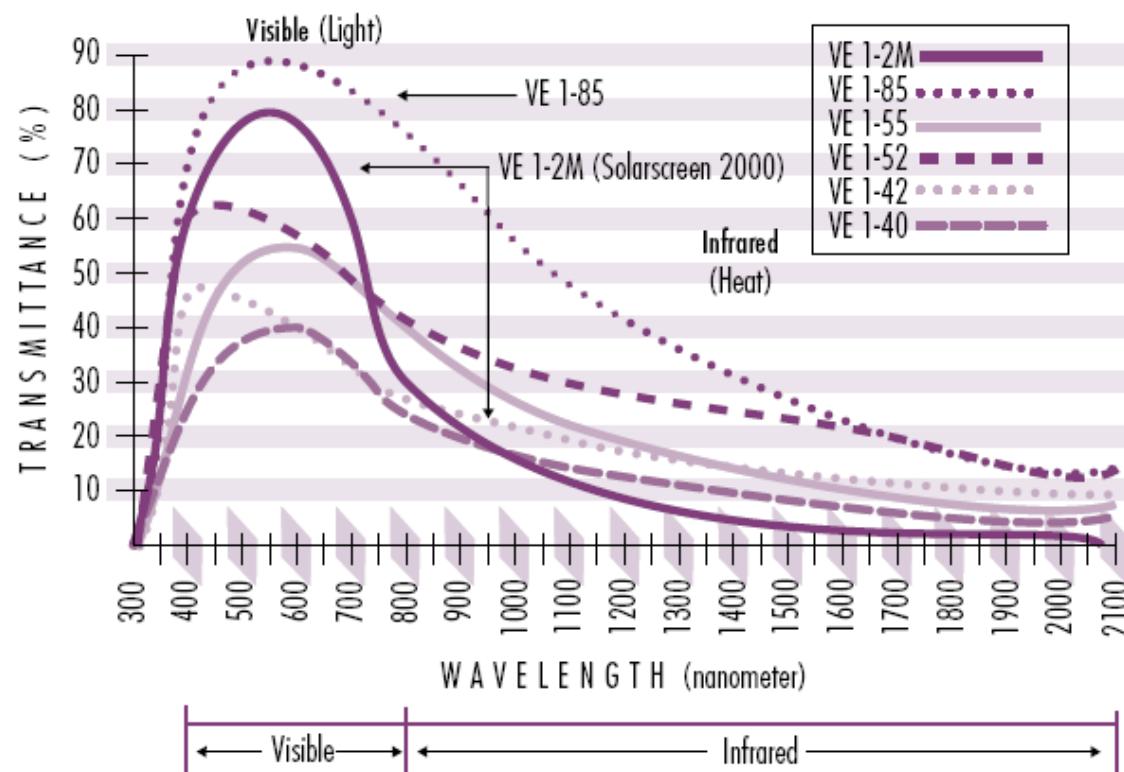
Triple-glazed with Low-Solar-Gain Low-E, Argon/Krypton Gas



<http://www.efficientwindows.org/index.cfm>



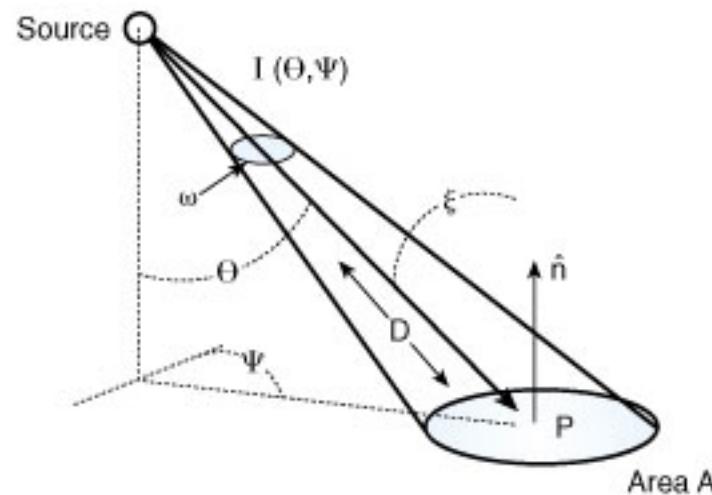
Spectrally Selective Glazing





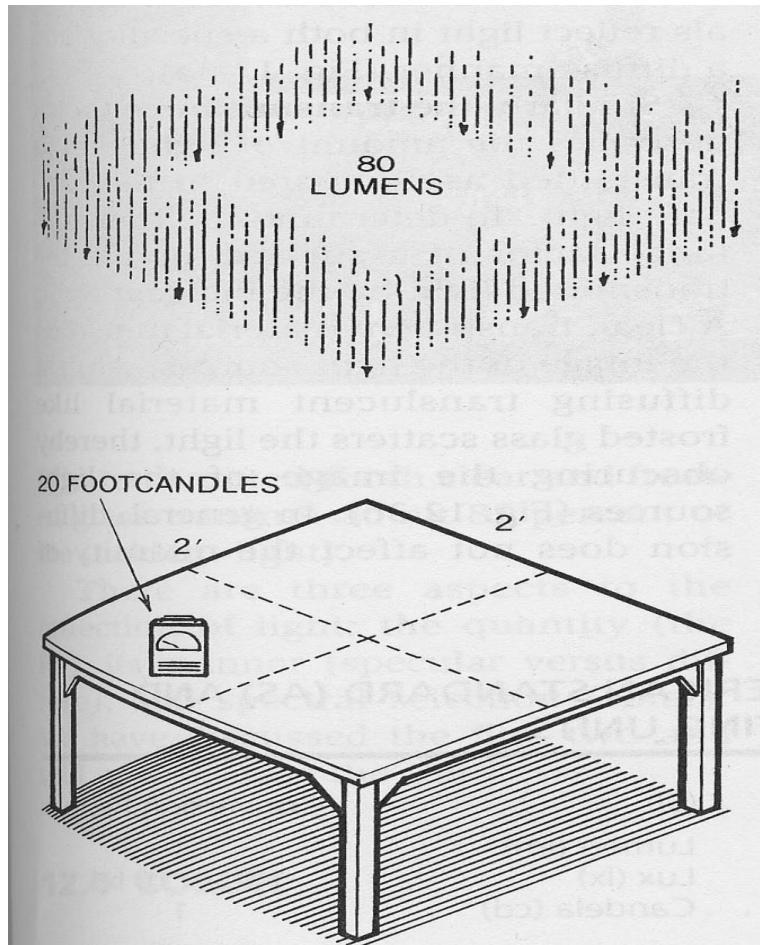
What is Illuminance?

- Amount of light striking a point on a surface.
[units: footcandle, lux (luminous flux per unit area
ex: lumen per SF)]





Illuminance (cont'd)



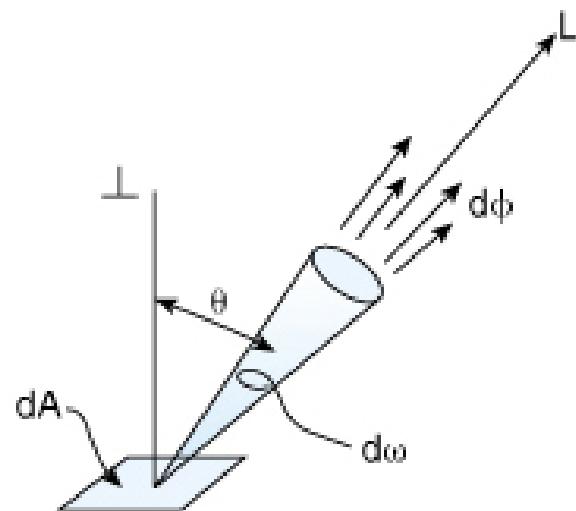
$$\text{Illuminance} = \text{Lumens}/\text{ft}^2$$

Illuminance: the number of lumens falling in each square foot of a surface.



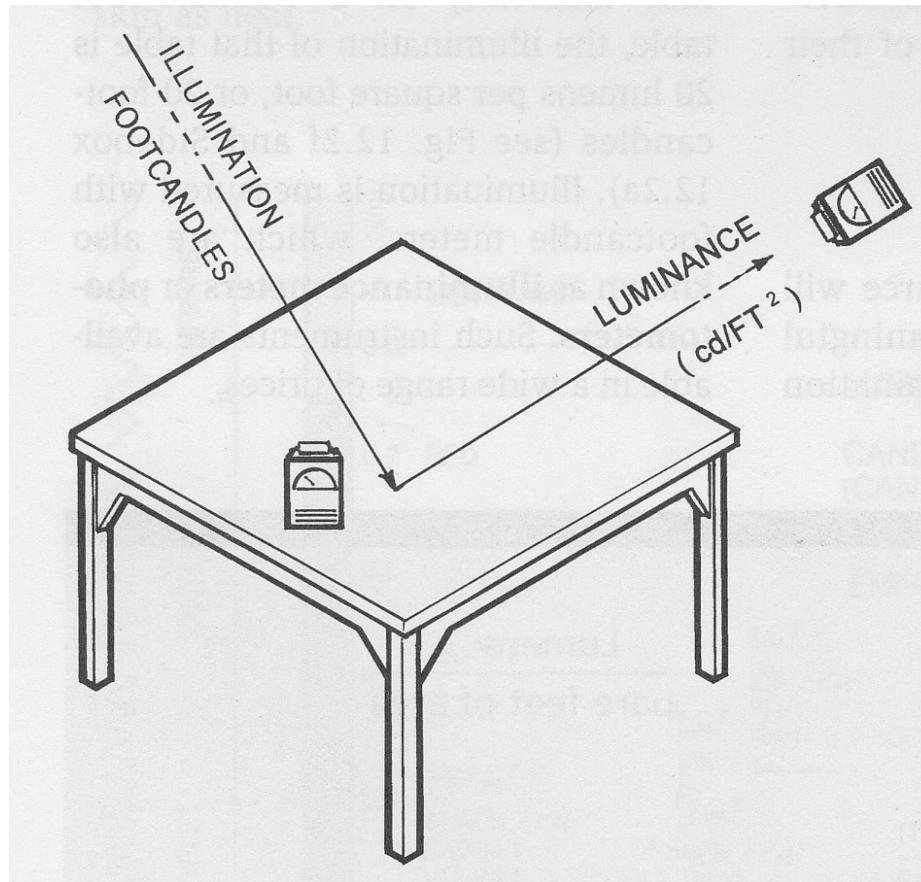
What is Luminance?

- **Luminance**, the amount of light reflected by a surface in a specific direction. [units: luminous intensity per area, ex. candelas/ SF]



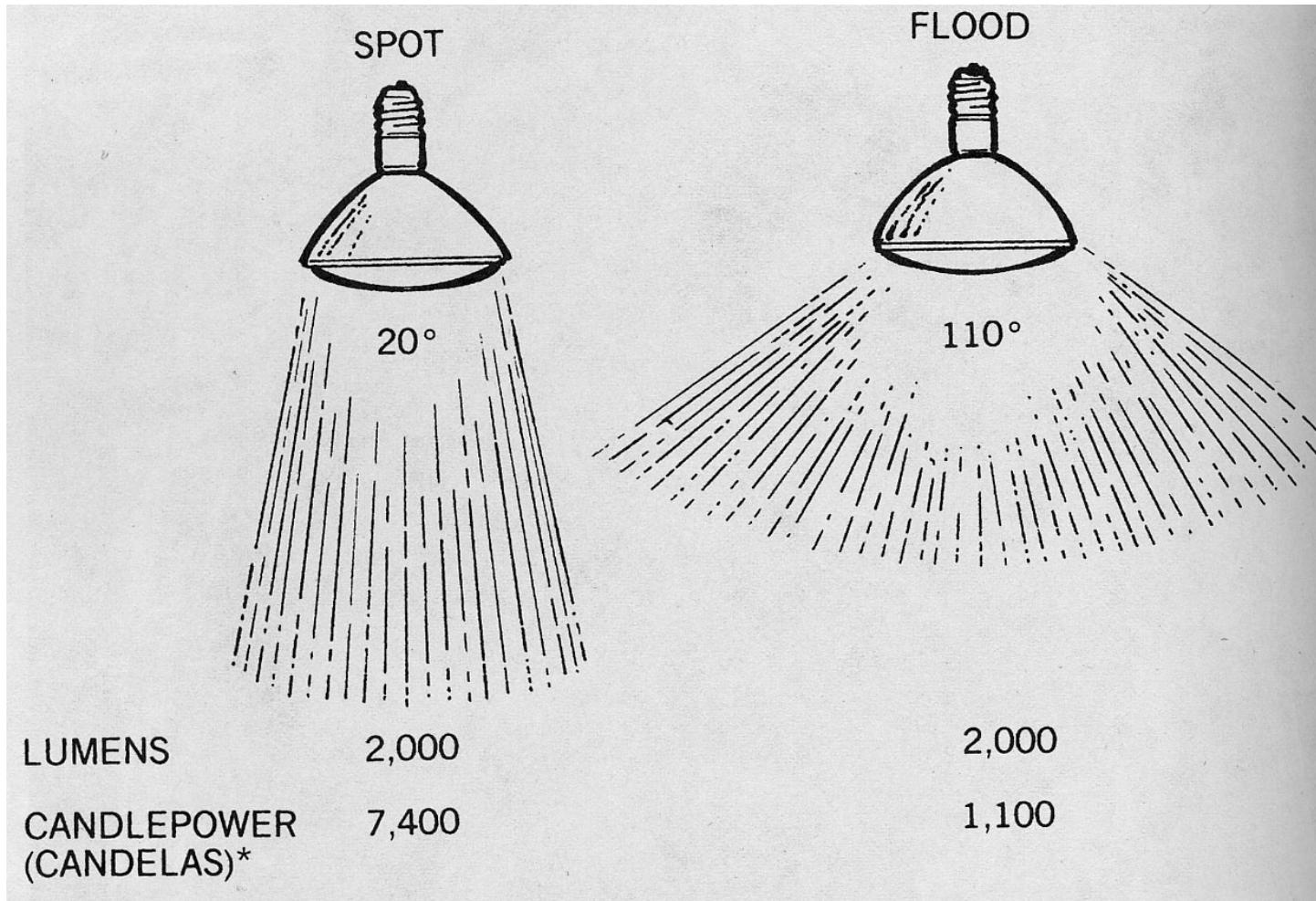


Illuminance vs. Luminance



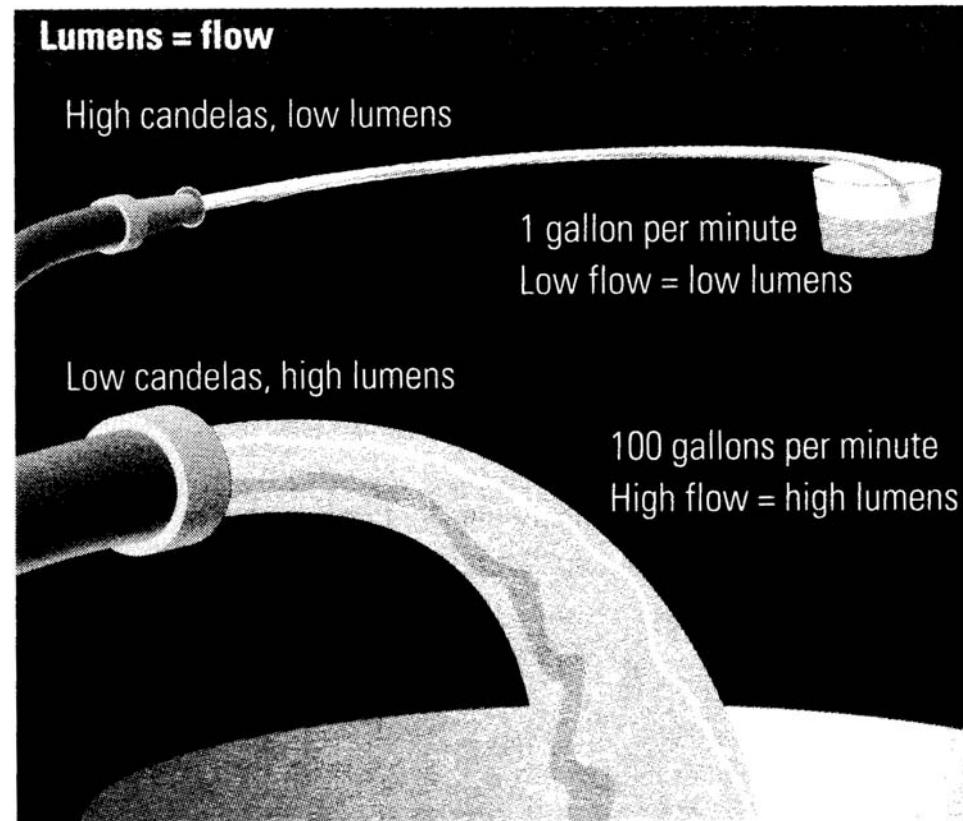


Light Output



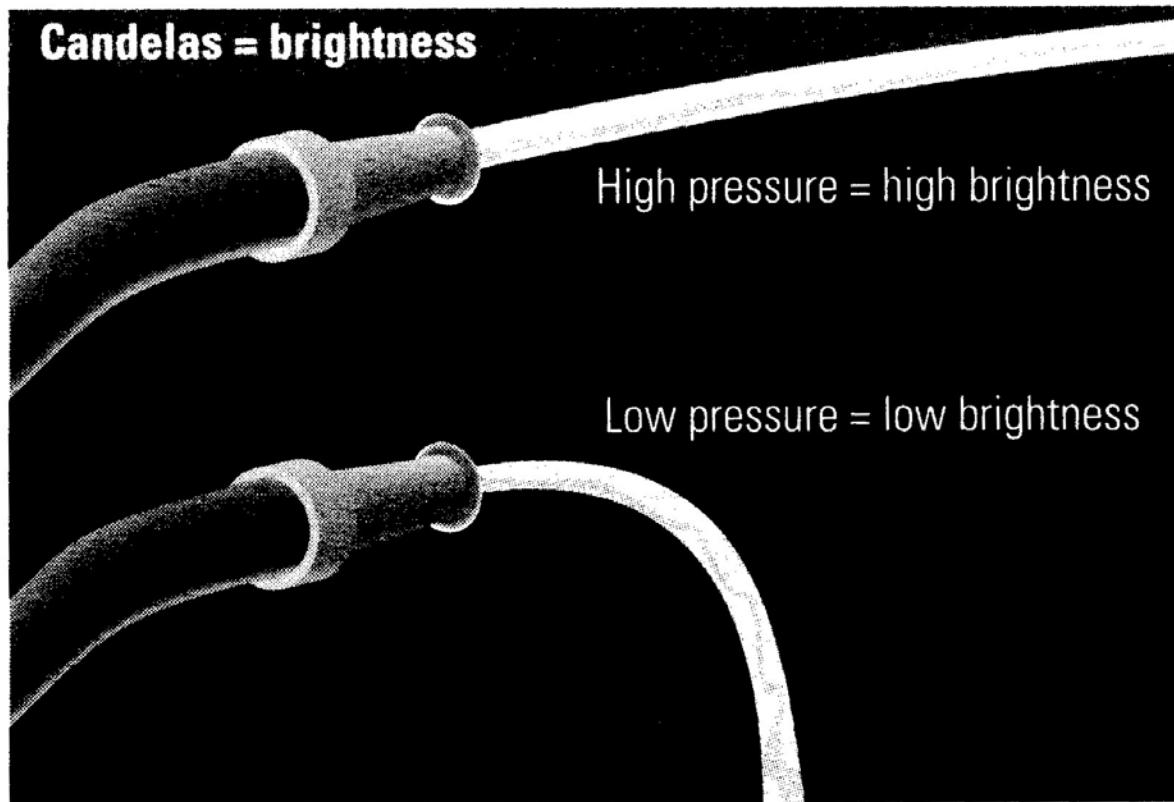


Lumens (Amount of Light)





Brightness (Intensity of Light)

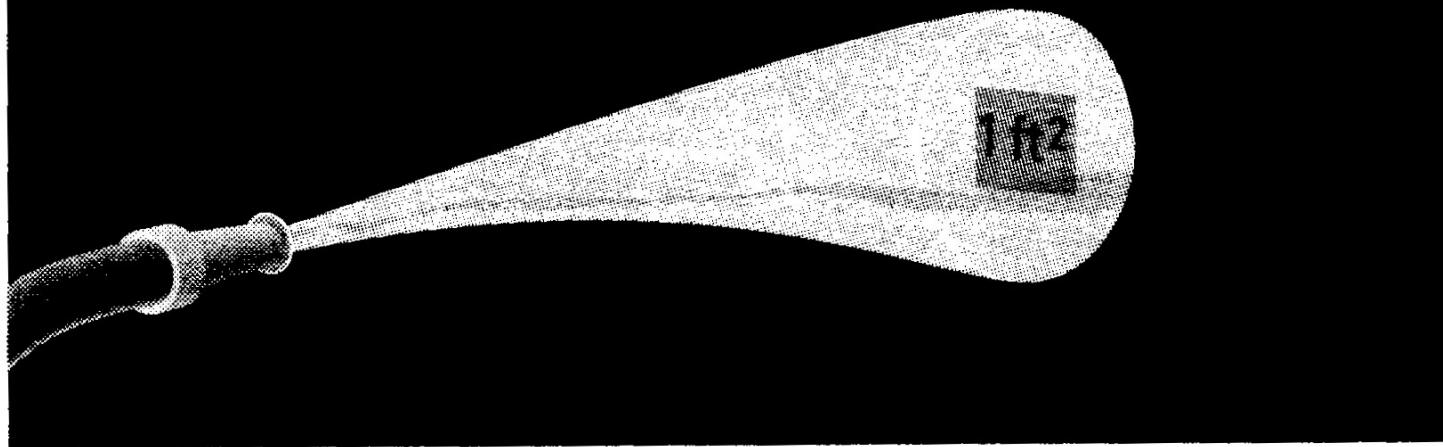




Illuminance (Light Arriving at a Surface)

Footcandles

Amount of spray hitting 1 ft^2 = footcandles



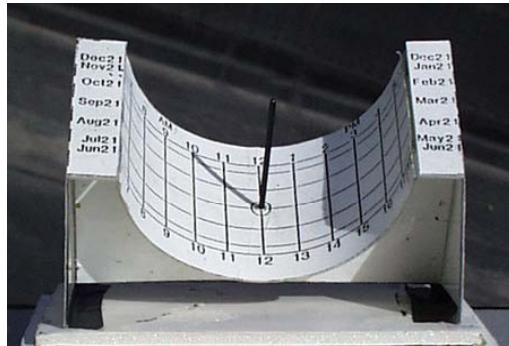


Lighting Units

Measure	Unit
Luminous Flux	Lumen
Illuminance	Footcandle = lumen / ft ²
Luminous Intensity	Candela
Luminance	Candela / unit area

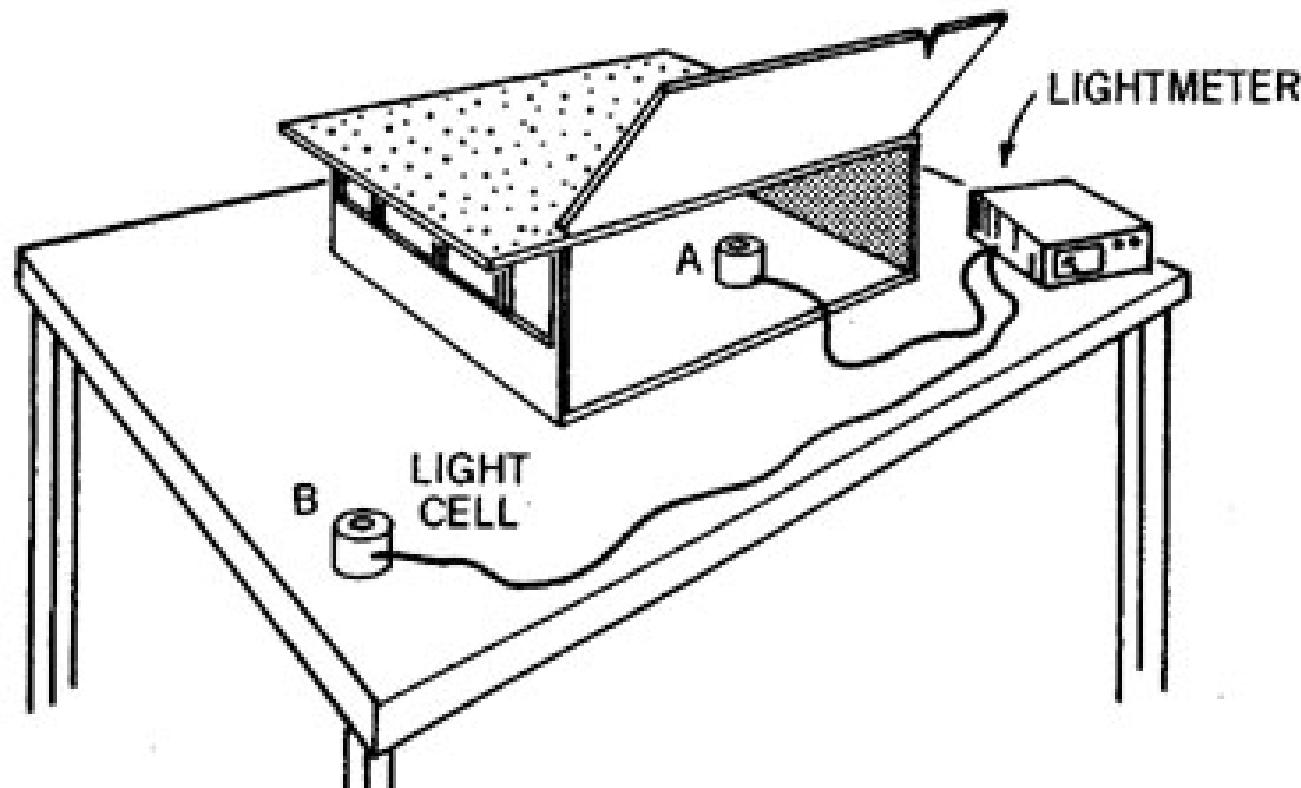


Physical Daylighting Models





Illuminance Measurements





Advantages of using a computer...

- Easy Changes (modifiable).
- Internal or external obstructions can be handled easily.
- Material and glazing properties.
- Controlled weather conditions.

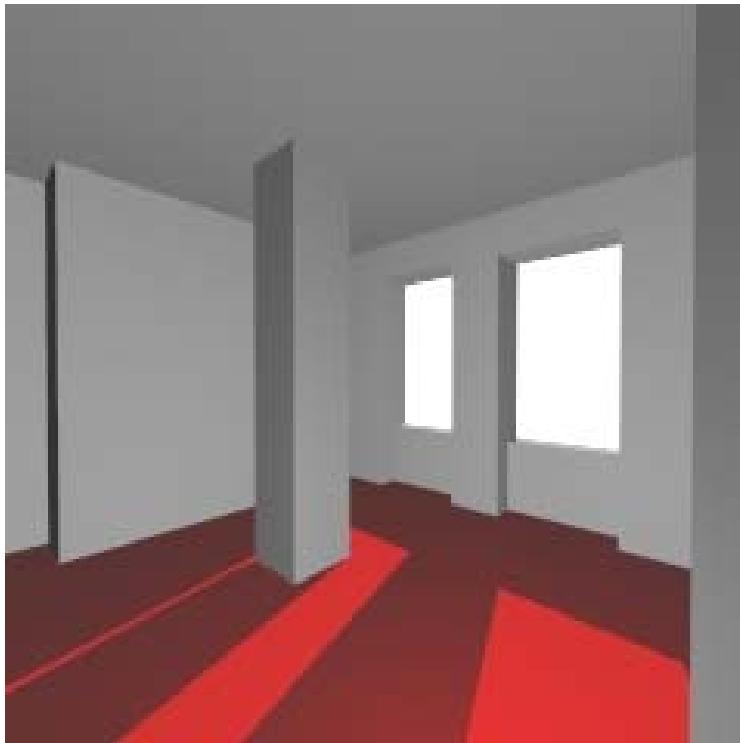


Basic Daylight Model Inputs

- Solar resource (location, date, weather)
- Geometry (interior and exterior)
- Building orientation
- Surface properties (reflectances, specularity)
- Glazing properties
- Solar control strategies



Radiosity vs. Ray Tracing



Radiosity

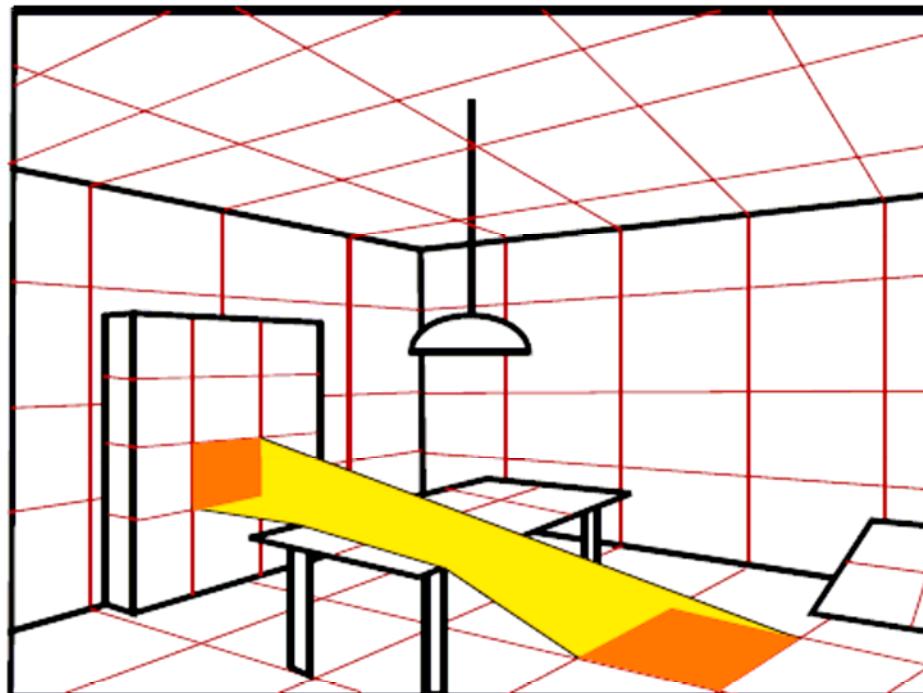


Backward Ray Tracing



Radiosity

- Diffuse surfaces
- Subdivide scene
- Radiosity assumed constant over a patch
- Form-factor between patches
- Geometry and visibility
- Big Matrix system



MIT EECS 6.837, Cutler and Durand

4



Limitations of radiosity

- Diffuse only for basic method
 - Costly extension to specular
- Requires meshing
- Cost of visibility computation
 - If you send rays, why not use ray tracing?
- Memory consumption vs. time scalability

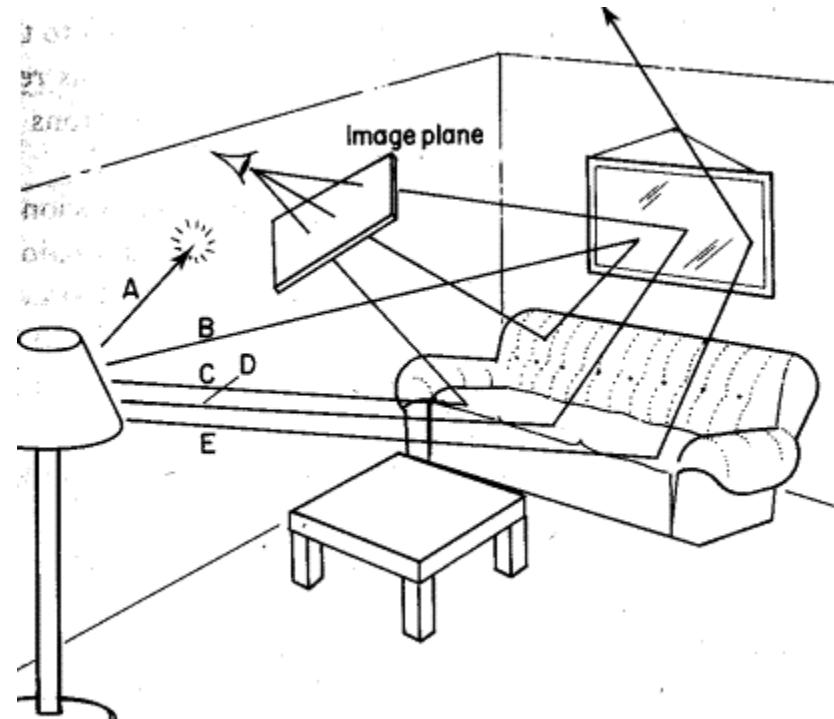
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MIT EECS 6.837, Cutler and Durand
http://ocw.mit.edu/NR/rdonlyres/Electrical-Engineering-and-Computer-Science/6-837Fall2003/69B1A6C4-511C-4CEE-8351-ED5B318FD940/0/19_montecarlo.pdf



Ray Tracing

- Handles specular reflections very well
- Best for rendering applications





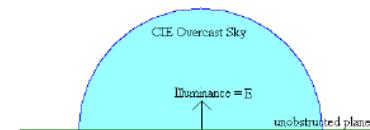
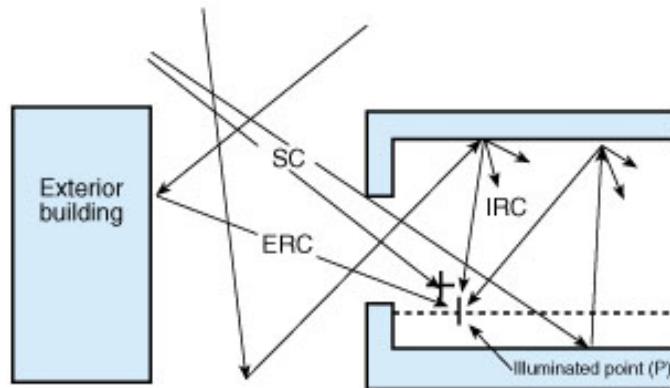
Summary of Modeling Outputs

- Illuminance levels
- Illuminance distribution
- Luminance ratios
- Glare probability
- Direct light penetration
- Performance metrics

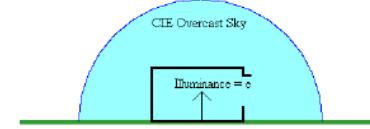


Daylighting Metrics- Daylight Factor (static)

- Ratio of the illuminance on the given plane at that point to the simultaneous exterior illuminance on a horizontal plane from the whole of an unobstructed sky.
- Daylight Factor (DF) = Sky + Reflected External + Reflected Internal
- Assumes an overcast sky for worse case conditions
- Most commonly used metric in daylighting design
- It is a poor metric for it does not take into account orientation, clear-sky days, and operating schedule



E = illuminance on unobstructed plane



e = illuminance at point in interior

Daylight Factor = e/E (often expressed as a percentage)

Illuminance is measured in LUX



Daylighting Metrics- Daylight Factor (dynamic)

- **Daylight Autonomy (DA):** the percentage of the year when a minimum illuminance threshold is met by daylight alone.
- **Useful Daylight Illuminances (UDI):** UDI results in three metrics: the percentages of the occupied times of the year when the UDI was achieved (100-2000lux), fell-short (<100 lux), or was exceeded (> 2000 lux).
- **Continuous Daylight Autonomy (DAcon):** like DA, but partial credit is attributed to time steps when the daylight illuminance lies below the minimum illuminance level. For example, in the case where 500 lux are required and 400 lux are provided by daylight at a given time step, a partial credit of $400\text{lux}/500\text{lux}=0.8$ is given for that time step.

Dynamic metrics are more useful for daylighting design for they account for operating schedule, varying sky conditions, and orientation

Dynamic Daylight Performance Metrics for Sustainable Building Design

Christoph F. Reinhart, John Mardaljevic, Zack Rogers



Daylighting Simulation Software

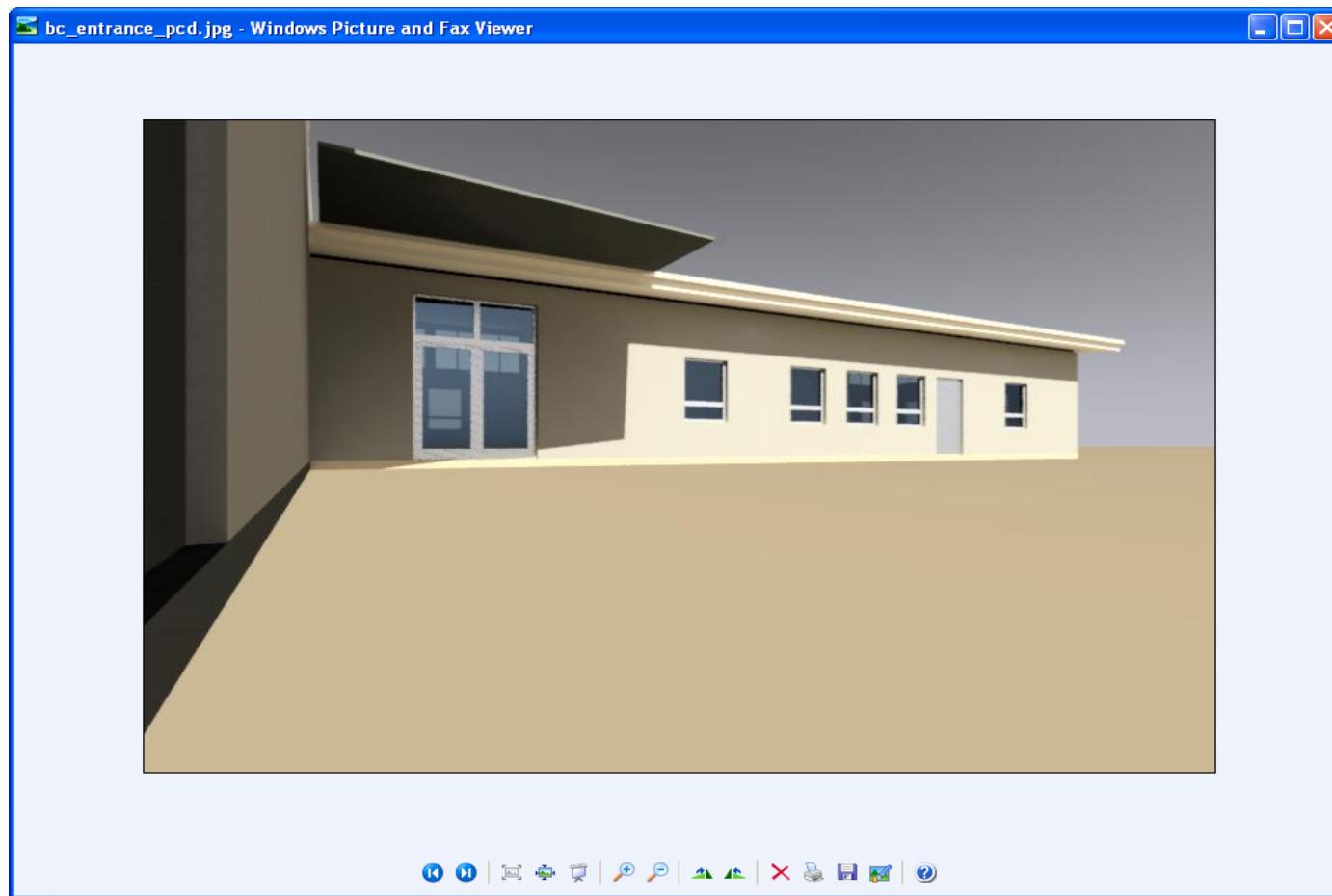
Software	Information	Cost	Comments
SPOT	http://www.archenergy.com/SPOT	Free	GUI to Radiance, Excel based, easy to use, dynamic
SkyCalc	http://www.energydesignresources.com/tools/skyclac.html	Free	Excel based, used for skylights
SuperLite	http://eetd.lbl.gov/btp/superlite20.html	Free	Radiosity, not used much
Trace-Pro	http://www.lambdares.com/	\$12,000	Good integration with CAD and CATIA but\$\$\$\$
Lumen Micro	http://www.lighting-technologies.com/	\$595	Radiosity, popular
ECOTECT	http://www.squ1.com/	\$90 Student License	DF calcs only, limited capabilities, exports to DAYSIM and Radiance
Radiance	http://radsite.lbl.gov/deskrad/	Free	Widely used simulation engine, no GUI, has both ray tracing and radiosity
Desktop Radiance	http://radsite.lbl.gov/deskrad/	Free	Not really functional at this time, old
Rayfront	http://www.schorsch.com/rayfront/	\$895	Website has been down all year
AGi32	http://www.agi32.com/	Free for us!	Radiosity, limited ray-tracing, very popular
DAYSIM	http://irc.nrc-cnrc.gc.ca/ie/lighting/daylight/daysim_e.html	Free	GUI to Radiance, good metrics, easy to use, dynamic



The pretty pictures you are all
waiting for....

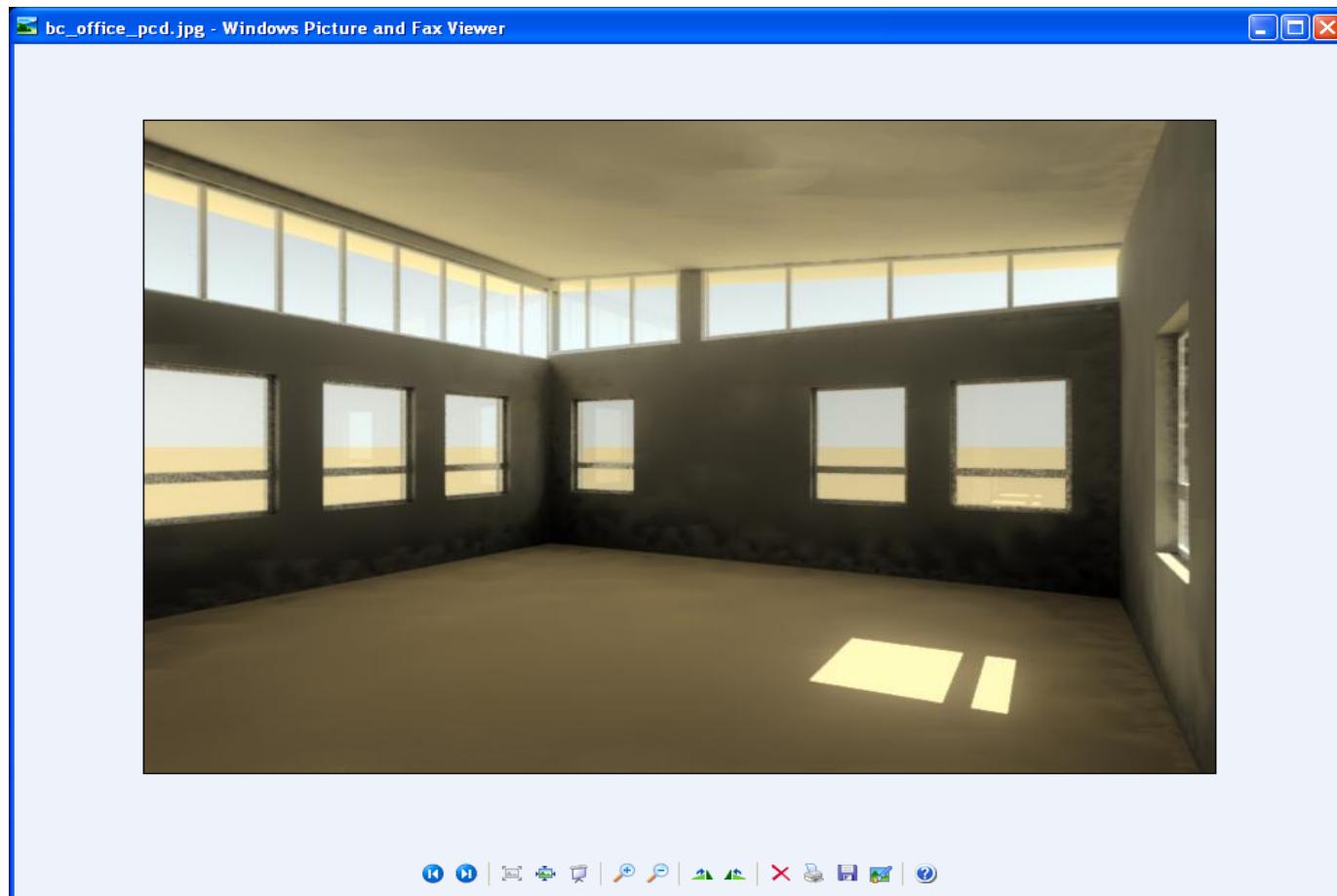


Radiance Modeling



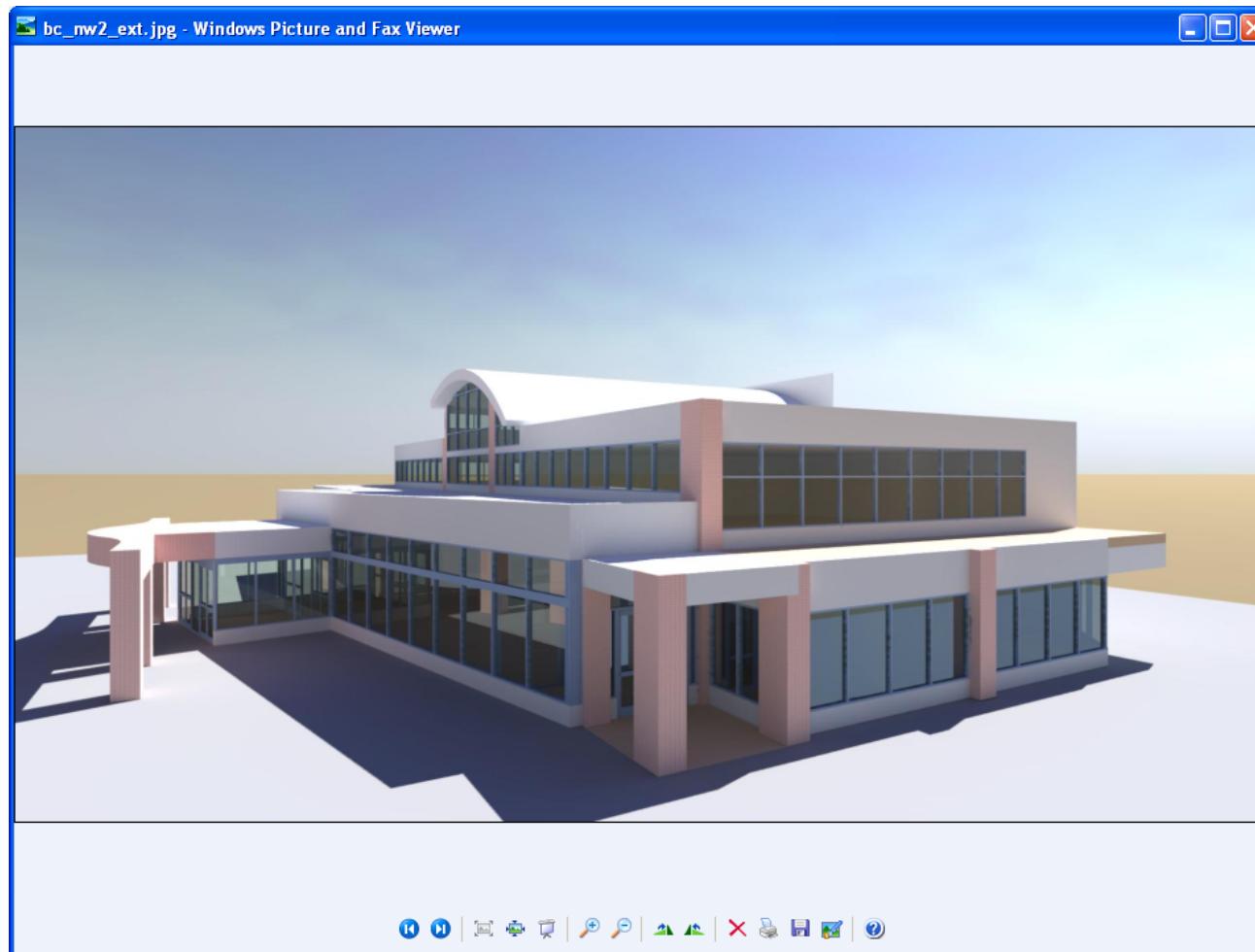


Radiance Modeling



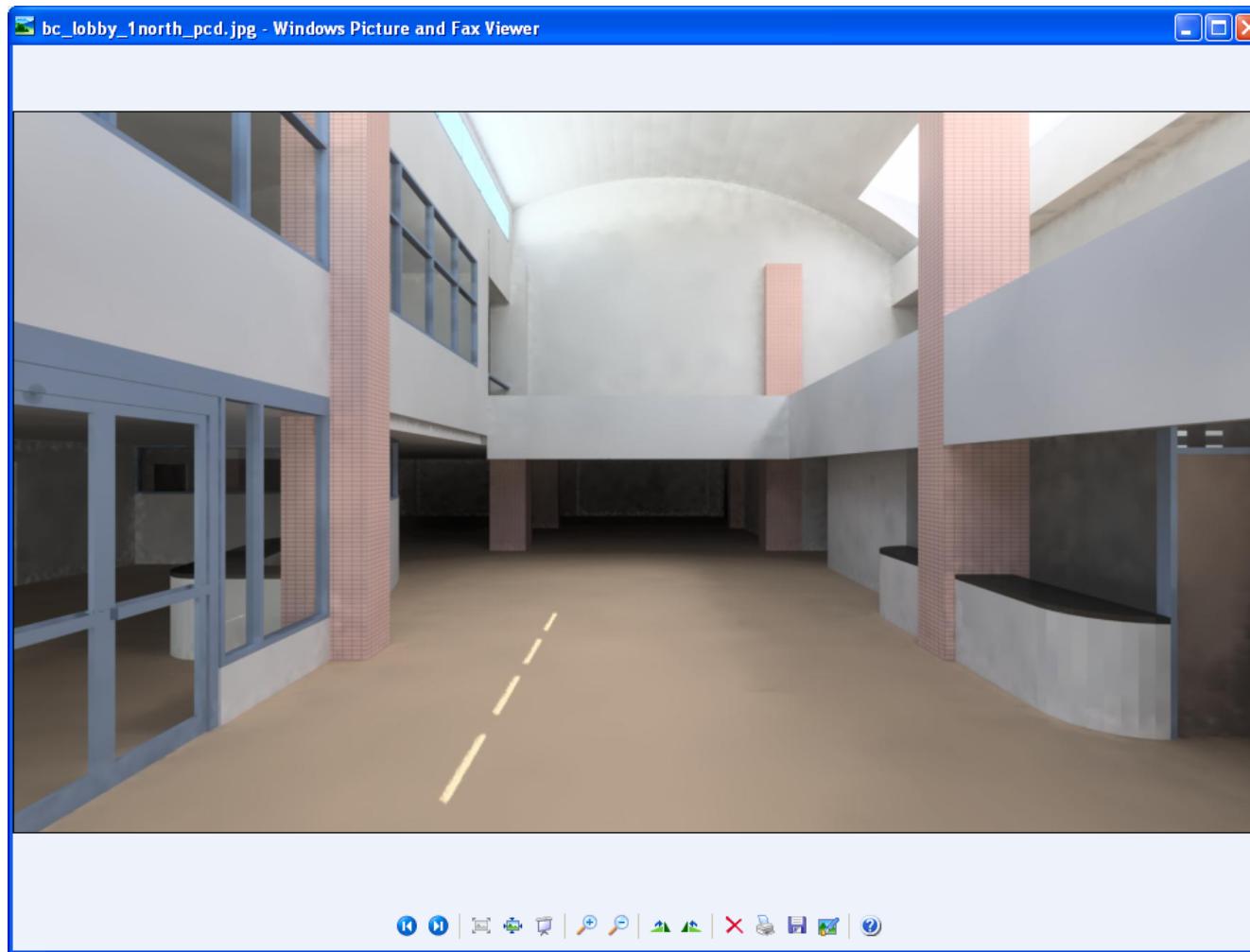


Radiance Modeling



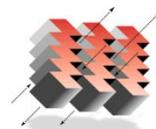


Radiance Modeling



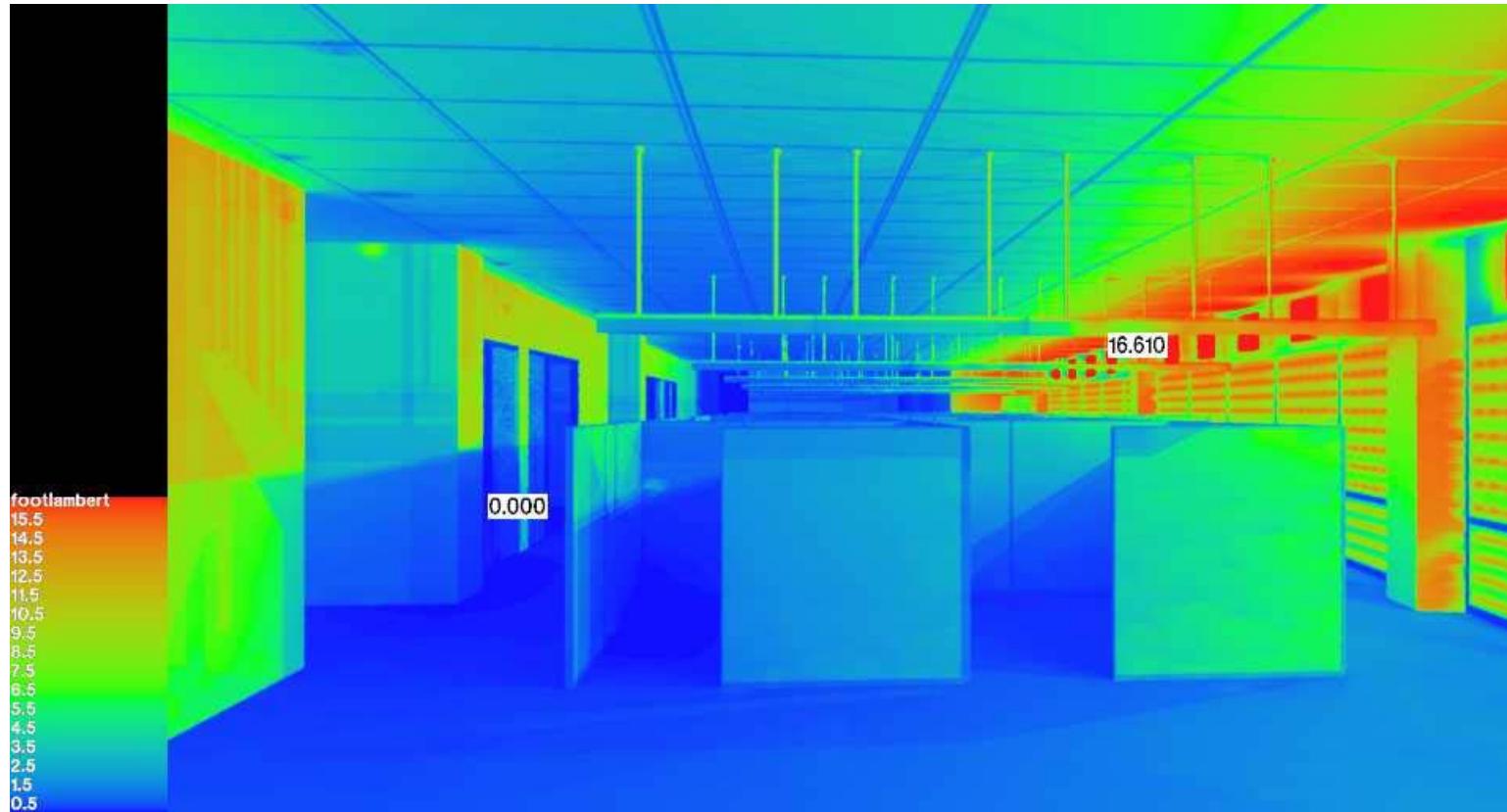


Radiance Modeling

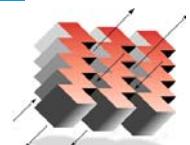




Radiance Simulation

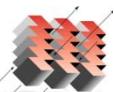
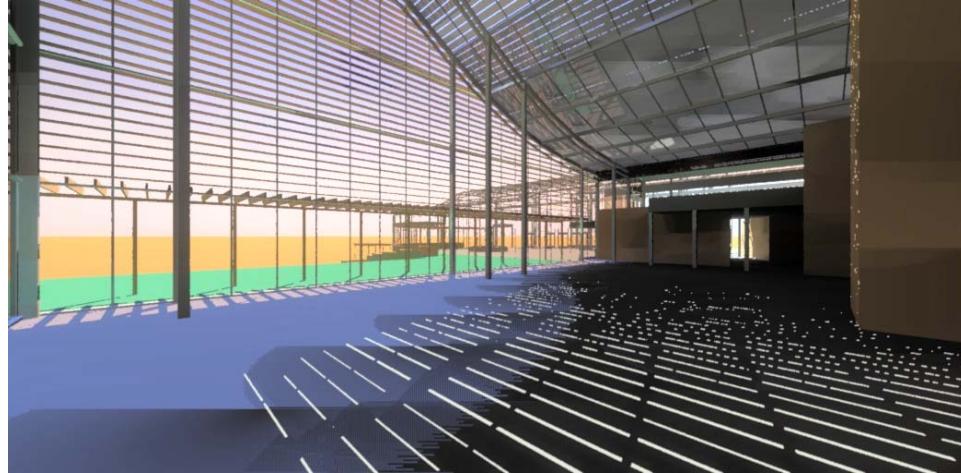


False Color Luminance Plot





Interior Luminous Environment

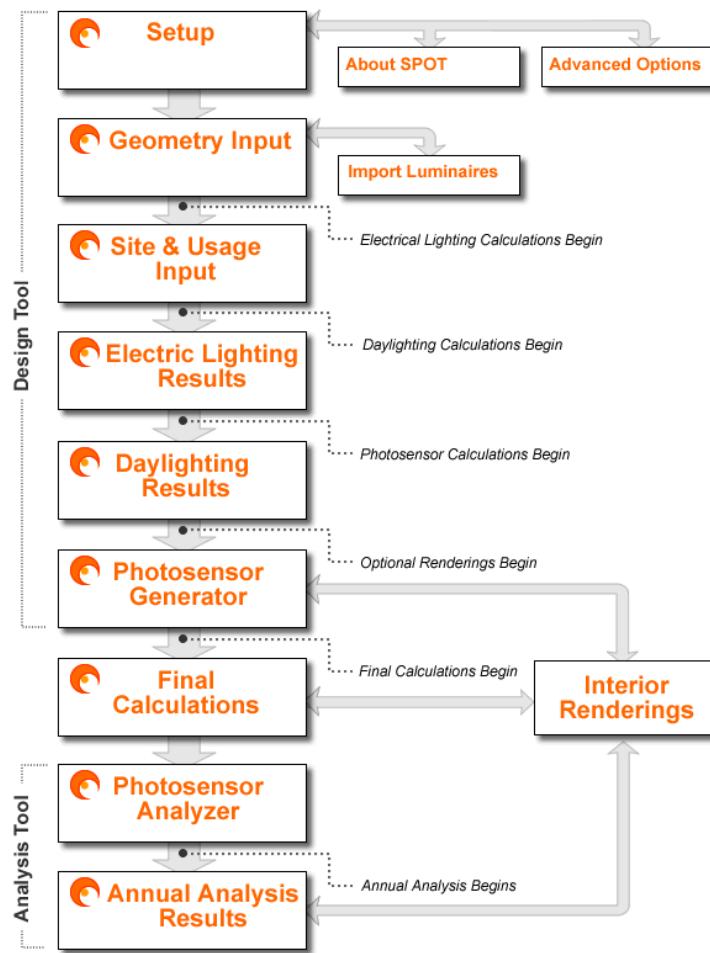




- Electric Lighting Analysis
- Annual Daylighting Analysis
- Photosensor Placement Optimization
- Photosensor System Optimization
- Annual System Performance Analysis



SPOT Modeling Process





SPOT- Geometric Input

SPOT **Geometry Input** [Run Interactive View](#) [**<< BACK**](#) [**NEXT >>**](#)

Spatial Characteristics

Dimensions

Width	28	ft
Length	32	ft
Height	11	ft

Flat **▼**

Workplane Height: 3.0 ft
Wall Thickness: 12 in
Skylight Depth: 3
Orientation: -20 deg

Surface Reflectances

Floor	30%	
Walls	65%	
Ceiling	80%	
Ground	25%	
Mullions	60%	
Lightshelves	50%	
Overhangs	80%	

Interactive Display - Overall Space

Compass

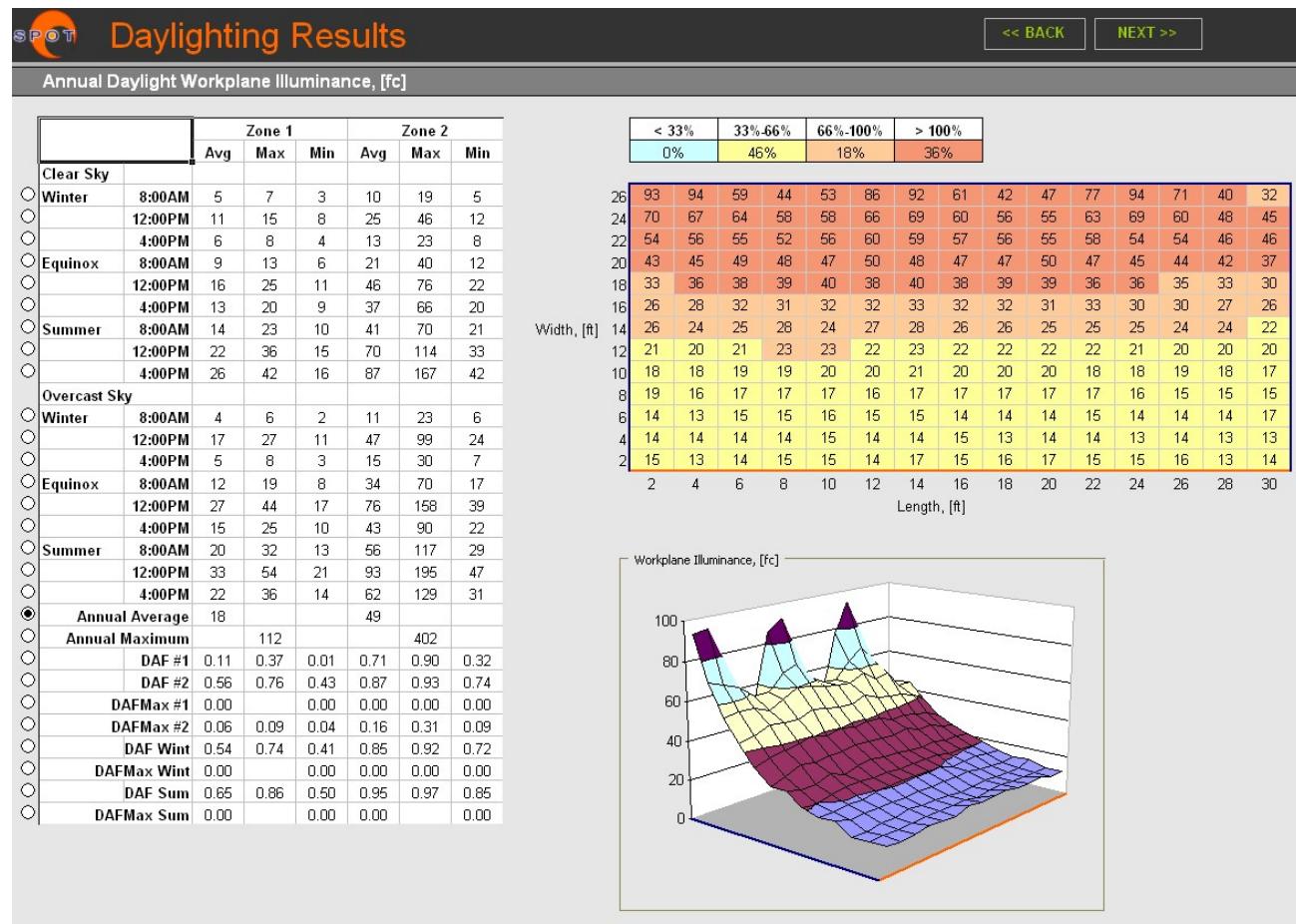
Space Isometric

Legend

- Walls
- South Wall
- Workplane
- Window
- Active Element
- Lightshelf
- Overhang

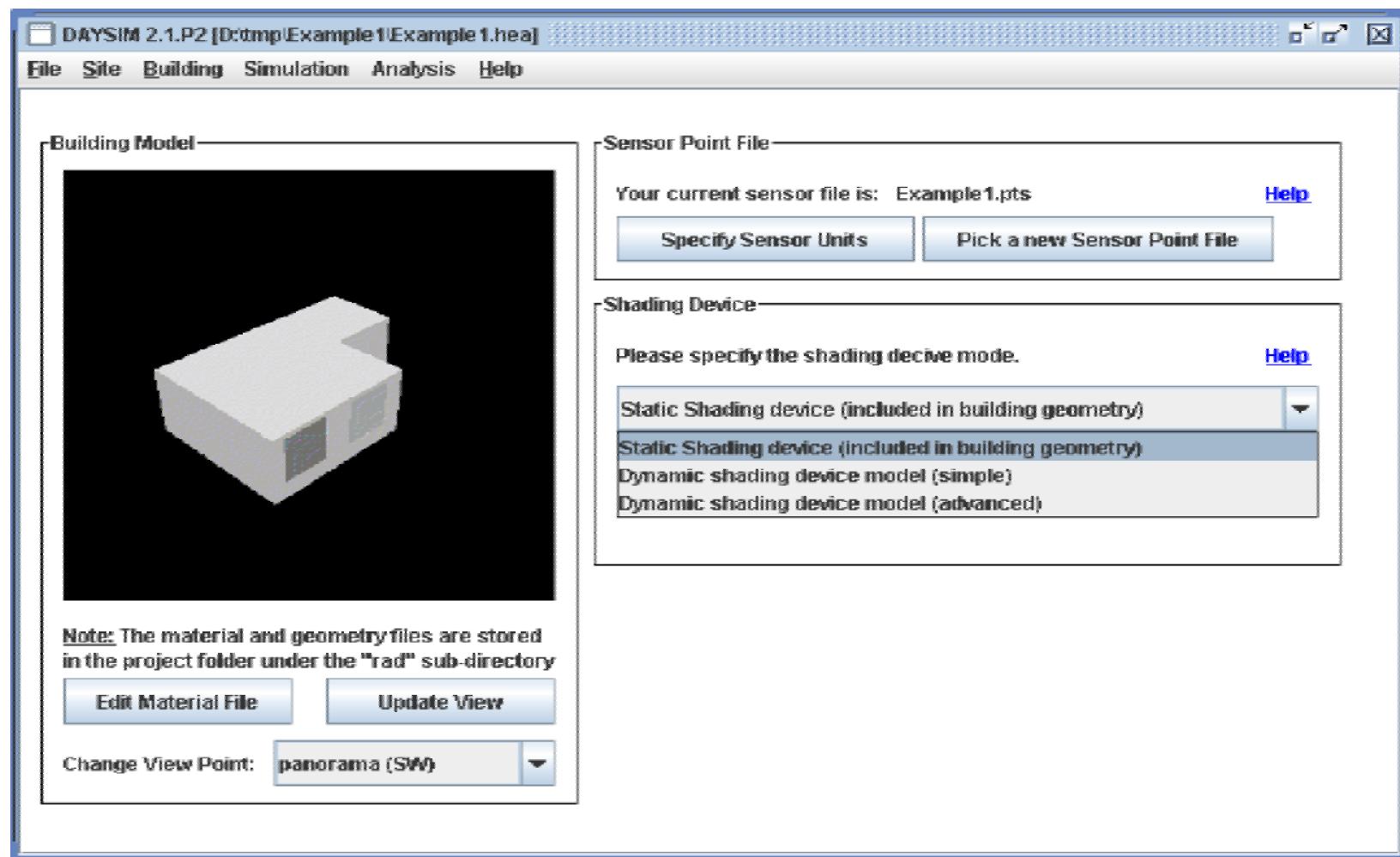


SPOT- Daylighting Results





DAYSIM- Geometry Import





DAYSIM- Simulation Parameters

DAYSIM 2.1.P2 [C:\DAYSIM\projects\test1\test1.jea]

File Site Building Simulation Analysis Help

Run Simulation... RADIANCE Simulation Parameters

Please choose the RADIANCE Simulation Parameters.

The Default RADIANCE Simulation Parameters are set as default values.

However, if you wish to use other RADIANCE Simulation Parameters, enter the desired parameter values in the appropriate text fields.

To Reload the Default RADIANCE Simulation Parameters, simply press the Load Default Values button.

<u>ambient bounces (ab)</u>	2	<u>specular jitter (sj)</u>	1.0000
<u>ambient divisions (ad)</u>	1000	<u>limit weight (lw)</u>	0.004000
<u>ambient super-samples (as)</u>	20	<u>direct jitter (dj)</u>	0.0000
<u>ambient resolution (ar)</u>	300	<u>direct sampling (ds)</u>	0.200
<u>ambient accuracy (aa)</u>	0.1	<u>direct relays (dr)</u>	2
<u>limit reflection (lr)</u>	6	<u>direct pretest density (dp)</u>	512
<u>specular threshold (st)</u>	0.1500		

Load Default Values Help



DAYSIM- Define Building Info

DAYSIM 2.1.P2 [C:\DAYSIM\projects\test1\test1.hea]

File Site Building Simulation Analysis Help

View Daylighting Analysis Results

Zone Description: 'zone 8'

Occupancy Profile:

Arrival Time: 08.00
Departure Time: 17.00
Lunch & Intermediate Breaks:
Daylight Savings Time:

User Requirements and Behavior:

Minimum Illuminance Level: 500
User Behaviour:
Lighting Use: Mix of Both
Blind Use: Mix of Both

Lighting and Shading Control System:

Installed Lighting Power Density: 1.5
Zone Size: 0.0
Blind Control: Manual
Lighting Control: Manual on/off switch near the door Specify Work Plane

Start Daylighting Analysis



DAYSIM- Simulation Report

DAYSIM Simulation Output - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

Back Forward Stop Refresh file:///D:/tmp/Example1/hcs/Example 1.e.htm

Customize Links Free Hotmail Windows Marketplace Windows Media Windows

Go

Daysim Simulation Report

Warning: No core workplane sensors have been selected. Daysim will therefore interpret all illuminance sensors as workplane sensors, i.e. Daysim assumes that the core workplane extends over all illuminance sensors in your lighting zone. (Note: To select a work plane sensor, go to ANALYSIS>>'SPECIFY WORKPLANE'.)

In short...

- **Daylight Factor (DF) Analysis:** 35% of all illuminance sensors have a daylight factor of 2% or higher. If the sensors are evenly distributed across 'all spaces occupied for critical visual tasks', the investigated lighting zone would not qualify for the LEED-NC 2.1 daylighting credit 8.1 as the area ratio of sensors with a daylight factor over 2% would need to be 75% or higher (see www.usgbc.org/LEED/).
- **Daylight Autonomy (DA) Analysis:** The daylight autonomies for all core workplane sensors lie between 0% and 91% for an active user and 0% and 75% for a passive user.
- **Useful Daylight Index (UDI) Analysis:** The Useful Daylight Indices for the Lighting Zone are UDI_{<100}=100%, UDI₁₀₀₋₂₀₀₀=0%, UDI_{>2000}=0% for an active user and UDI_{<100}=100%, UDI₁₀₀₋₂₀₀₀=0%, UDI_{>2000}=0% for a passive user.
- **Continuous Daylight Autonomy (DA_{con}) and DA_{max} Analysis:** 48% of all illuminance sensors have a DA_{con} above 40% for an active user and 29% of all sensors have a DA_{con} above 40% for a passive user. 1% of all illuminance sensors have a DA_{max} above 5% for an active user and 0% of all sensors have a DA_{max} above 5% for a passive user.
- **Electric Lighting Use:** The predicted annual electric lighting energy use in the investigated lighting zone is: 3.3 kWh/unit area.

Simulation Assumptions

Site Description: The investigated building is located in Toronto (43.70 N/ 79.60 W). Daylight savings time lasts from April 1st to October 31st.

User Description: The zone is occupied Monday through Friday from 8:00 to 17:00. The occupant leaves the office three times during the day (30 minutes in the morning, 1 hour at midday, and 30 minutes in the afternoon). The total annual hours of occupancy at the work place are 1569.0. The electric lighting is activated 2364.0 hours per year. The occupant performs a task that requires a minimum illuminance level of 500 lux. The coordinates of core work place sensors are marked in blue in the table below. (Core workplane sensors indicate where occupants are usually located within a lighting zone, e.g. a desk in an office.)

The predicted annual electric lighting energy use of 3.3 kWh/unit area corresponds to the mean energy use in an ensemble of identical offices that are occupied by four user types:

- a user who operates the electric lighting in relation to ambient daylight conditions, opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm⁻² hits the seating position (to avoid direct glare),
- a user who operates the electric lighting in relation to ambient daylight conditions, and keeps the blinds lowered throughout the year to avoid direct sunlight,
- a user who keeps the electric lighting on throughout the working day, opens the blinds in the morning (upon arrival), and lowers them when direct sunlight above 50 Wm⁻² hits the seating position (to avoid direct glare), and
- a user who keeps the electric lighting on throughout the working day, and keeps the blinds lowered throughout the year to avoid direct sunlight.

Lighting and Blind Control: The electric lighting system has an installed lighting power density of 1.50 W/unit area and is manually controlled with an on/off switch. A simplified shading device model is used that assumes that the lowered blinds block all direct sunlight and transmit 25 percent of all diffuse daylight. (This simplified model is adequate for the initial design phase.) The shading device is manually operated.

Done



DAYSIM- Simulation Parameters (cont'd)

Detailed Simulation Results

The table below shows the daylight factor and various dynamic daylight performance metrics for all sensor points individually. Definitions of these quantities are provided in chapter one of the Daysim Tutorial. To guide the reader's eye, the following color code is used:

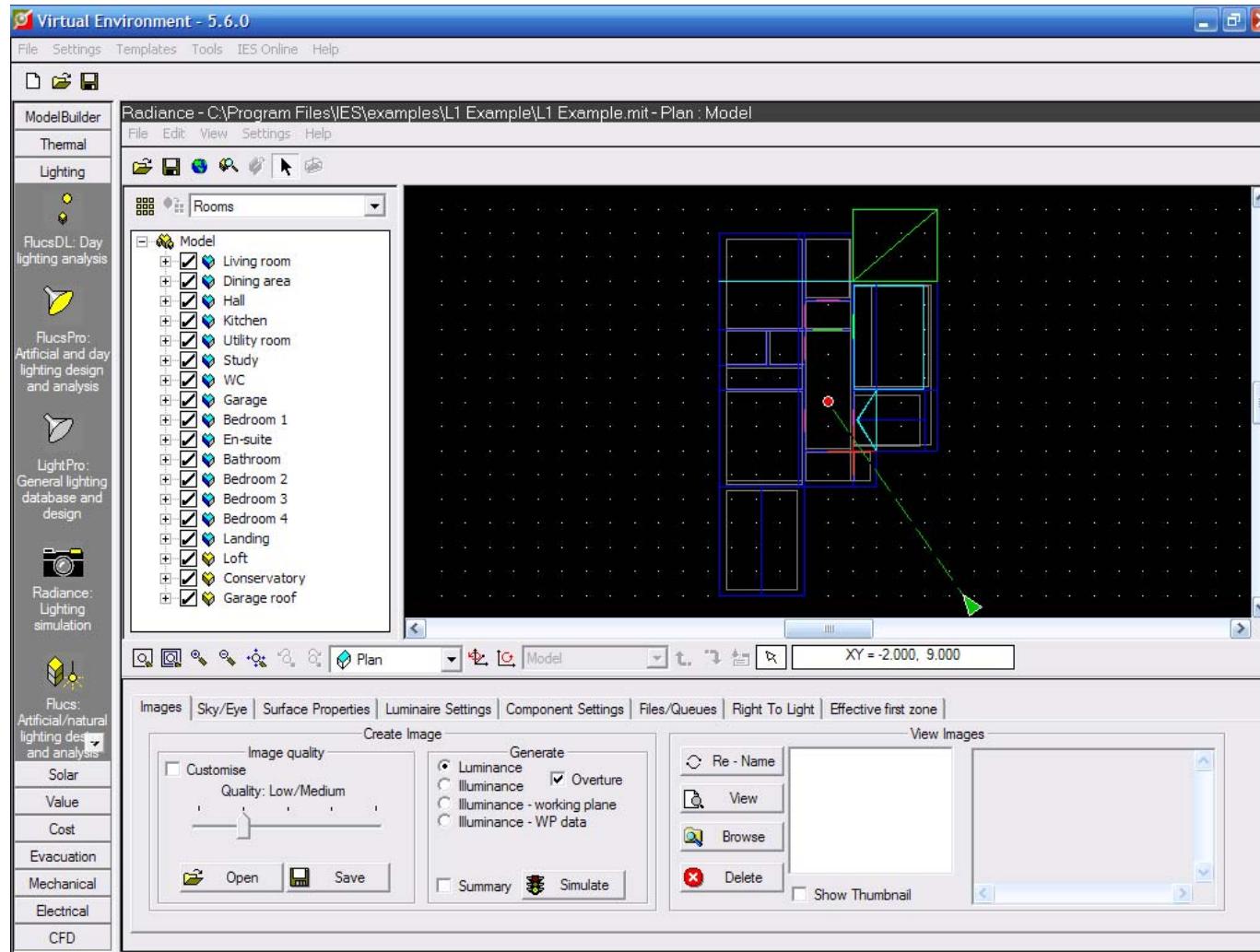
- Coordinates of core workplane sensors are shown in blue .
- Daylight factor levels over 2% are shown in green.
- Annual light exposure levels of medium and high sensitivity (CIE Categories III and IV) are shown in dark green and light green .

x	y	z	DF (%) (active)	DA (%) (passive)	DAcon (%) (active)	DAcon (%) (passive)	DAmax (%) (active)	DAmax (%) (passive)	UDI<100 (%) (active)	UDI<100 (%) (passive)	UDI<100-2000 (%) (active)	UDI<100-2000 (%) (passive)	UDI>2000 (%) (active)	UDI>2000 (%) (passive)	annual light exposure [luxh]	
2.225	2.188	0.600	2.5	32	14	84	47	0	0	10	26	85	75	6	0	1617730
2.675	2.188	0.600	2.9	81	62	92	81	3	0	3	8	74	88	24	6	4867381
3.125	2.188	0.600	15.4	87	69	94	84	3	0	2	7	87	82	31	11	5588481
3.675	2.188	0.600	15.0	87	69	94	84	2	0	2	0	00	81	32	13	5038241
4.025	2.188	0.600	3.8	84	64	93	81	1	0	2	7	73	85	26	7	4834989
4.475	2.188	0.600	1.8	40	17	72	51	0	0	7	21	83	79	0	0	1684954
4.925	2.188	0.600	1.8	9	0	43	28	0	0	17	38	93	82	0	0	772526
5.375	2.188	0.600	2.2	15	0	63	33	0	0	13	31	87	89	0	0	998238
5.825	2.188	0.600	2.9	20	0	65	45	0	0	9	25	91	75	0	0	1346005
6.275	2.188	0.600	2.0	21	0	66	46	0	0	9	25	81	75	0	0	1388171
6.725	2.188	0.600	2.8	20	0	69	44	0	0	9	26	91	74	0	0	1308018
7.175	2.188	0.600	2.0	13	0	49	31	0	0	15	33	85	87	0	0	315785
7.625	2.188	0.600	1.0	2	0	28	16	0	0	37	62	63	38	0	0	473400
2.225	2.563	0.600	2.8	68	48	85	73	1	0	4	13	84	87	13	0	3588808
2.675	2.563	0.600	3.8	86	69	94	84	4	0	2	8	87	82	32	11	5820294
3.125	2.563	0.600	7.5	90	75	96	87	5	0	1	5	54	73	46	22	7195356
3.675	2.563	0.600	17.8	91	75	96	87	5	0	1	5	51	71	48	25	7228196
4.025	2.563	0.600	4.8	88	70	90	84	3	0	1	0	04	79	36	15	5887128
4.475	2.563	0.600	2.3	71	43	83	72	0	0	2	12	82	88	5	0	3266608
4.925	2.563	0.600	3.4	42	18	75	55	0	0	7	20	83	80	0	0	1770418
5.375	2.563	0.600	3.3	22	1	68	48	0	0	9	24	91	70	0	0	1440930
5.825	2.563	0.600	3.3	22	0	70	50	0	0	8	23	92	77	0	0	1510497
6.275	2.563	0.600	3.2	21	0	69	49	0	0	9	23	91	77	0	0	1486467
6.725	2.563	0.600	2.9	20	0	64	45	0	0	9	25	81	75	0	0	1338719
7.175	2.562	0.600	2.3	15	0	63	24	0	0	13	21	87	89	0	0	1008757
7.625	2.563	0.600	1.5	5	0	39	23	0	0	20	42	90	50	0	0	802201
2.225	2.938	0.600	7.5	70	50	87	73	1	0	4	12	84	88	13	0	3581244
2.675	2.938	0.600	11.0	81	63	92	81	3	0	2	8	74	88	24	6	4917462
3.125	2.938	0.600	2.0	87	70	94	93	3	0	2	8	88	93	39	10	5830517
3.675	2.938	0.600	3.2	87	69	94	84	3	0	1	5	68	83	30	11	5576517
4.025	2.938	0.600	1.5	84	64	93	81	2	0	2	7	77	88	21	5	4802083
4.475	2.938	0.600	3.0	72	45	83	73	0	0	3	12	82	88	5	0	3270048
4.925	2.938	0.600	2.2	55	29	82	68	0	0	5	16	94	84	1	0	2202956
5.375	2.938	0.600	2.8	37	14	74	54	0	0	7	21	89	79	0	0	1662768
5.825	2.938	0.600	2.2	55	0	68	48	0	0	8	24	94	82	0	0	1486554

Done

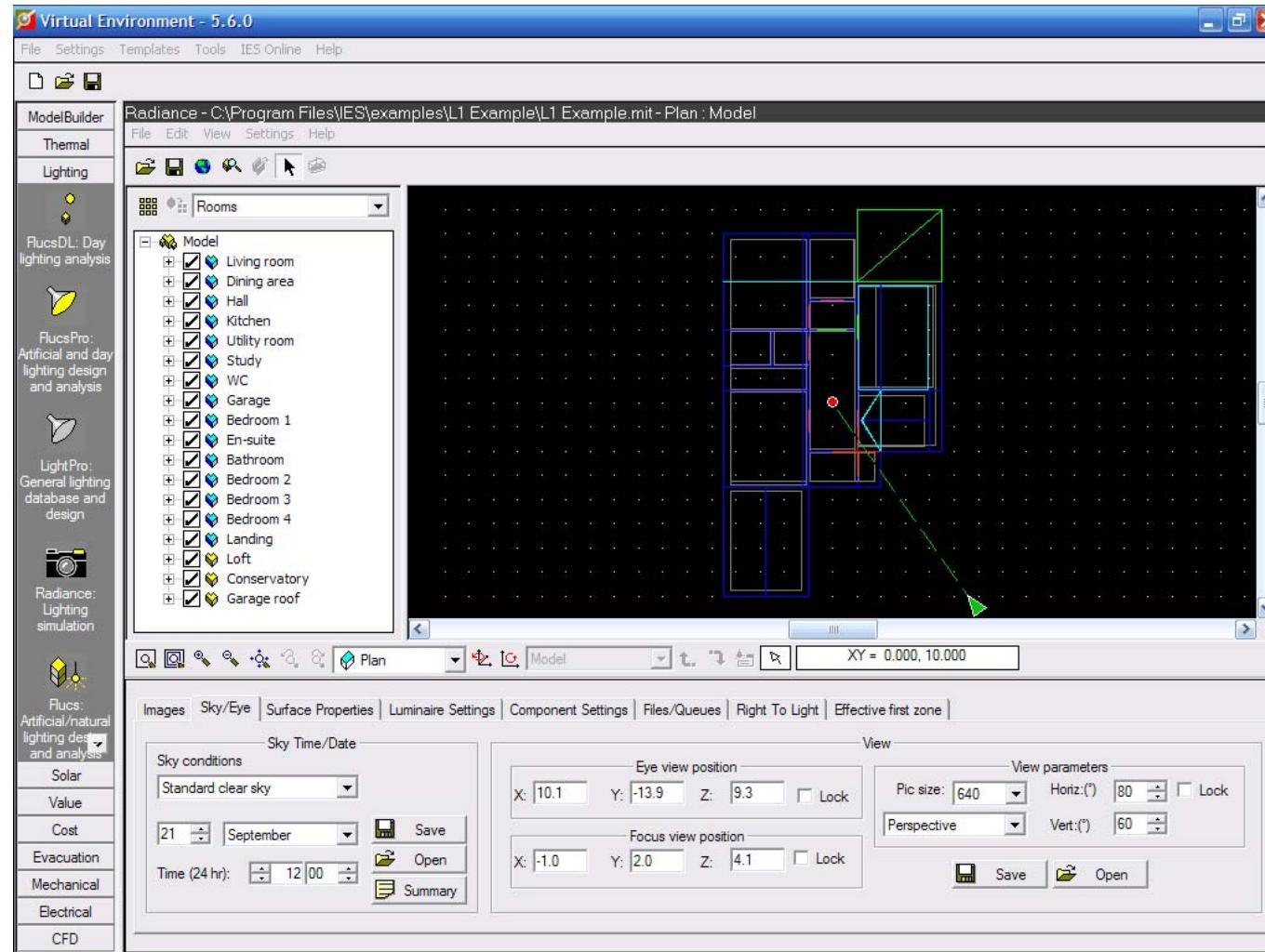


IES- Radiance



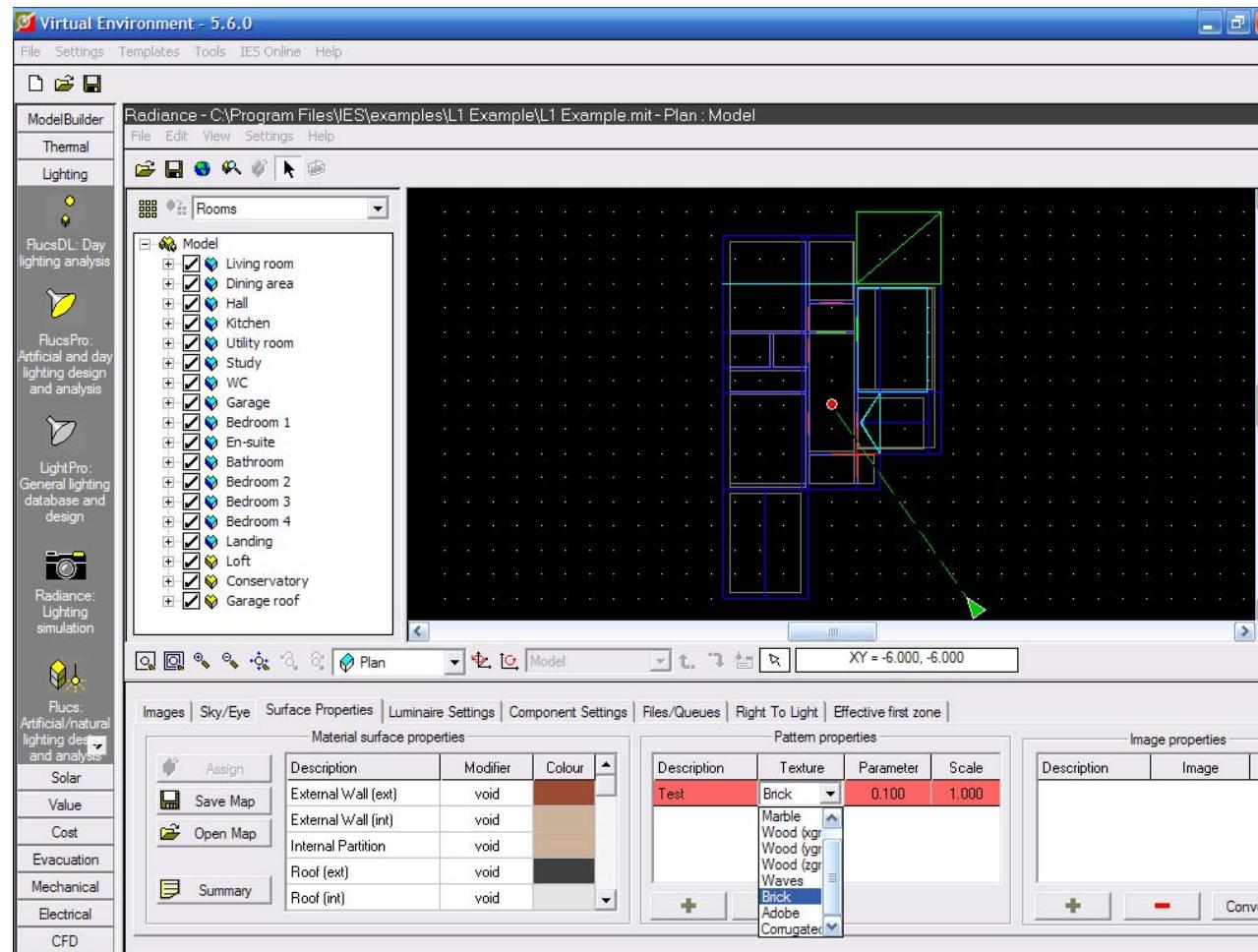


IES- Sky and Eye



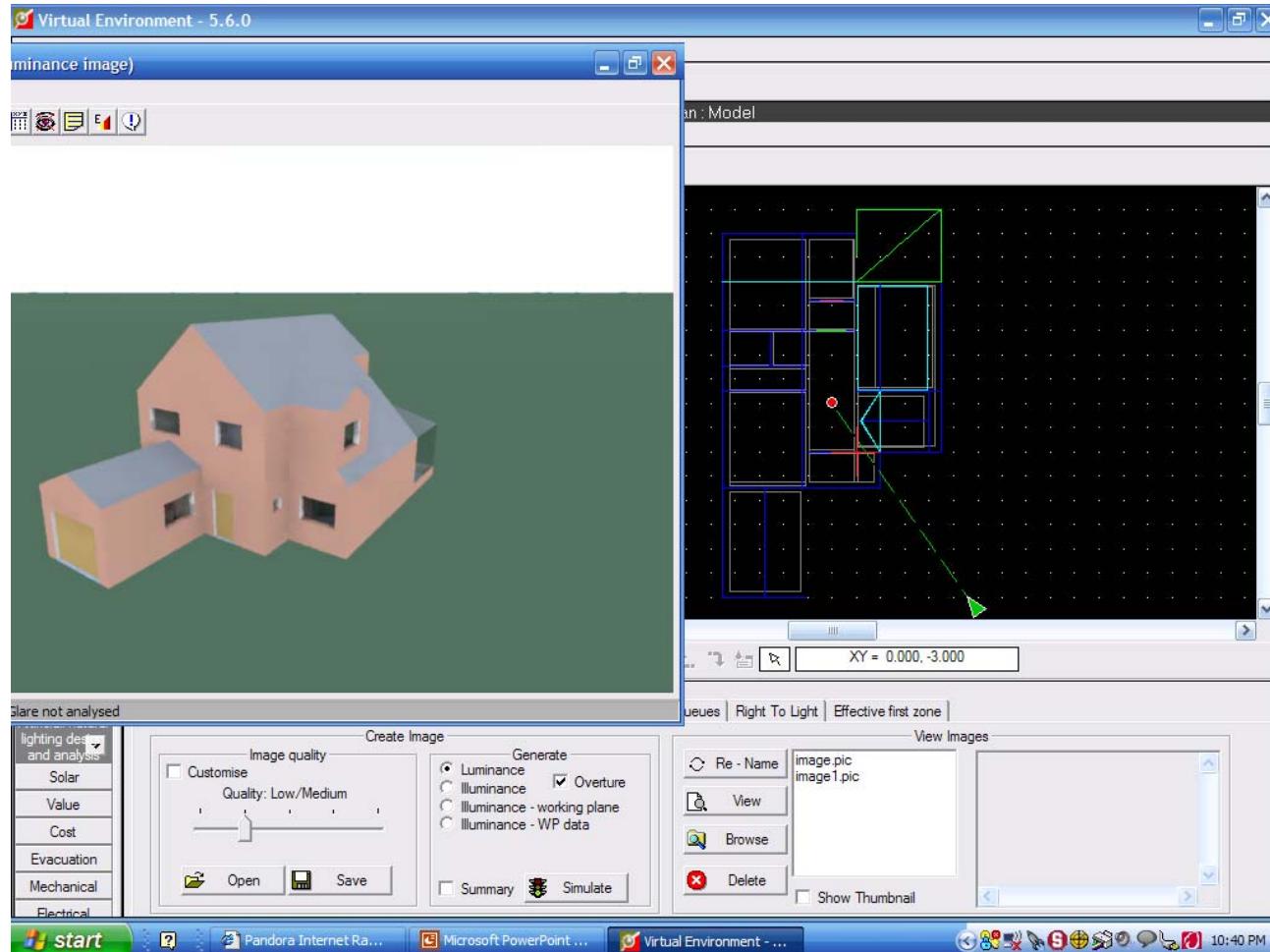


IES- Surface Properties



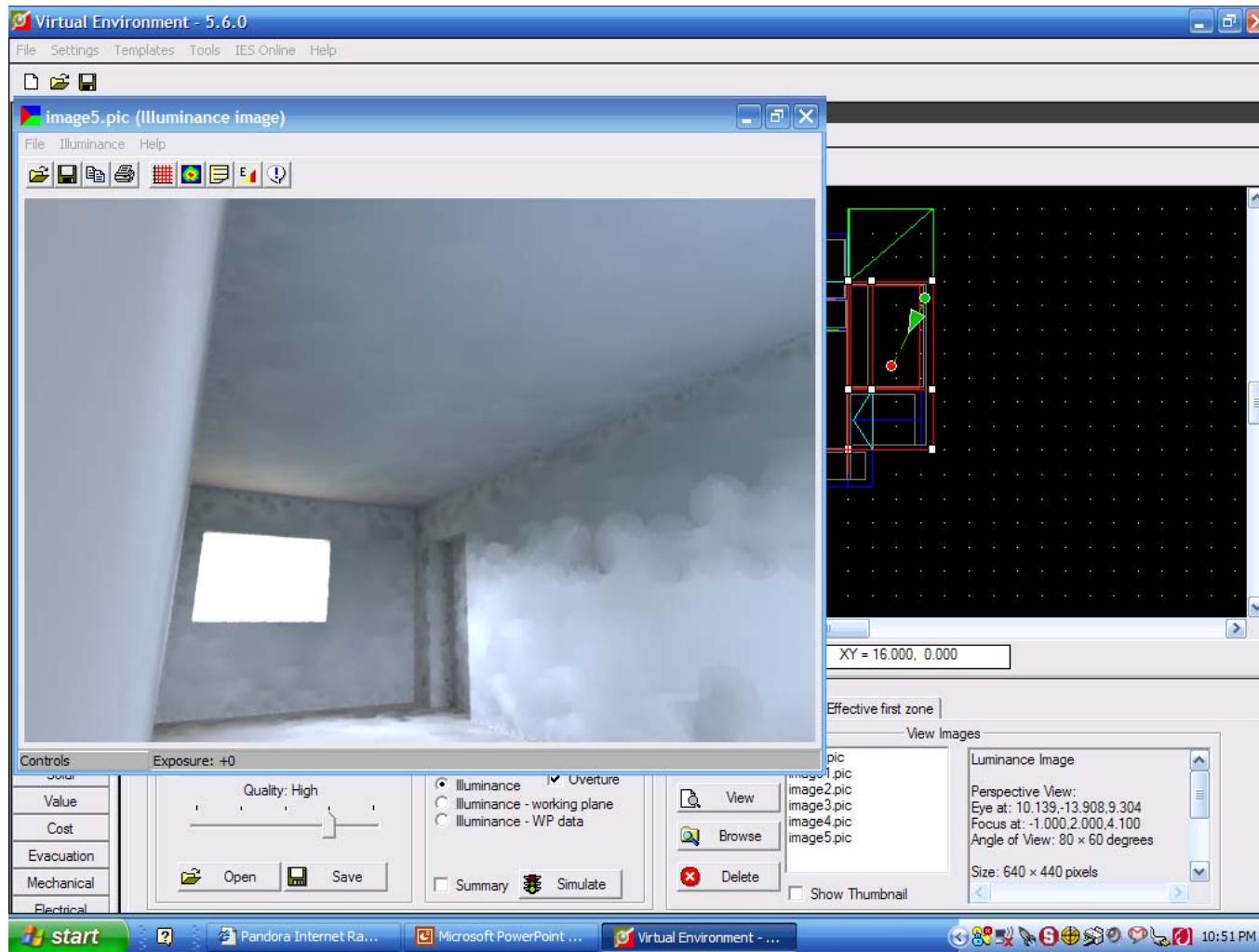


IES - Luminance Exterior



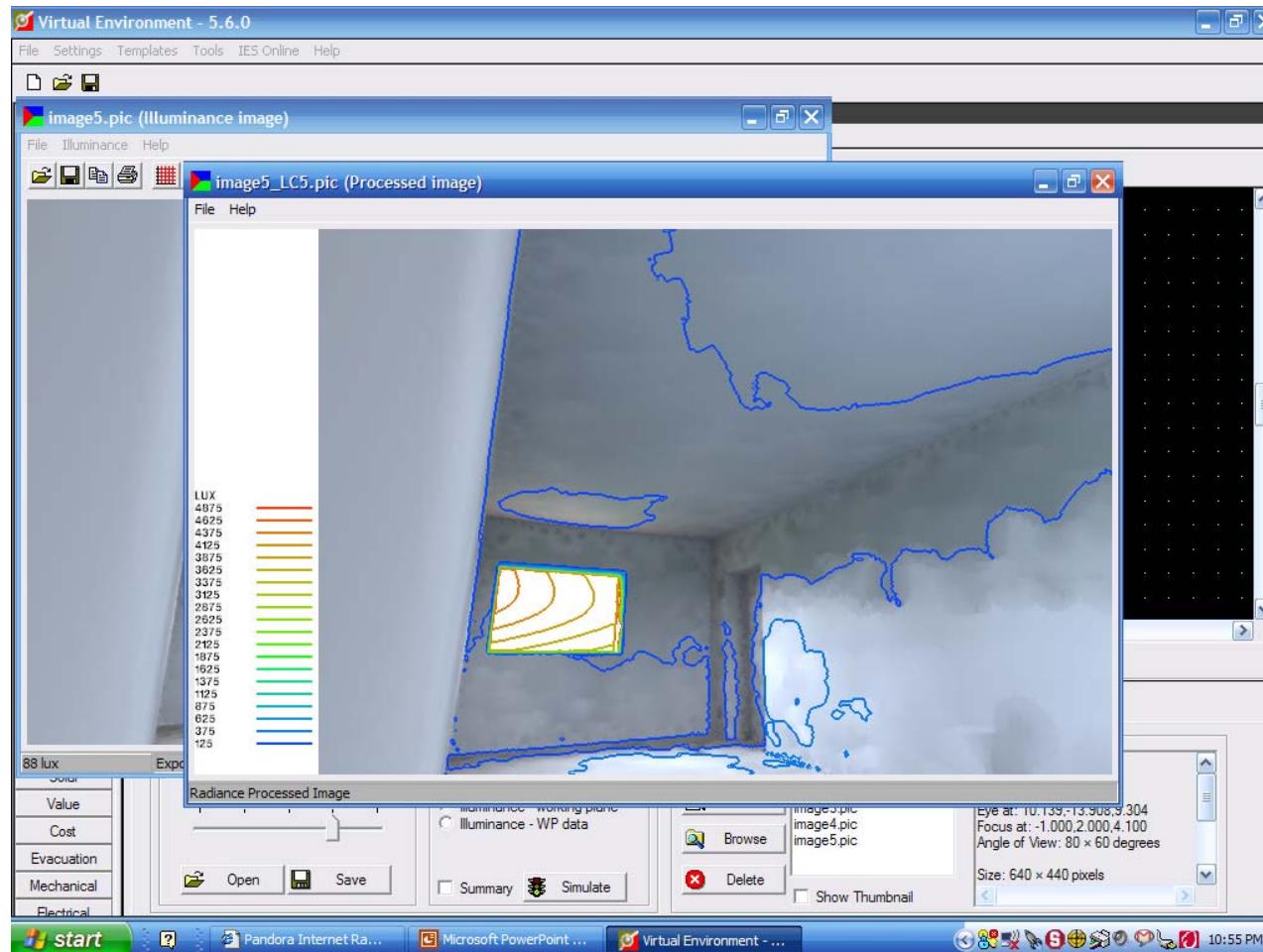


IES- Illuminance



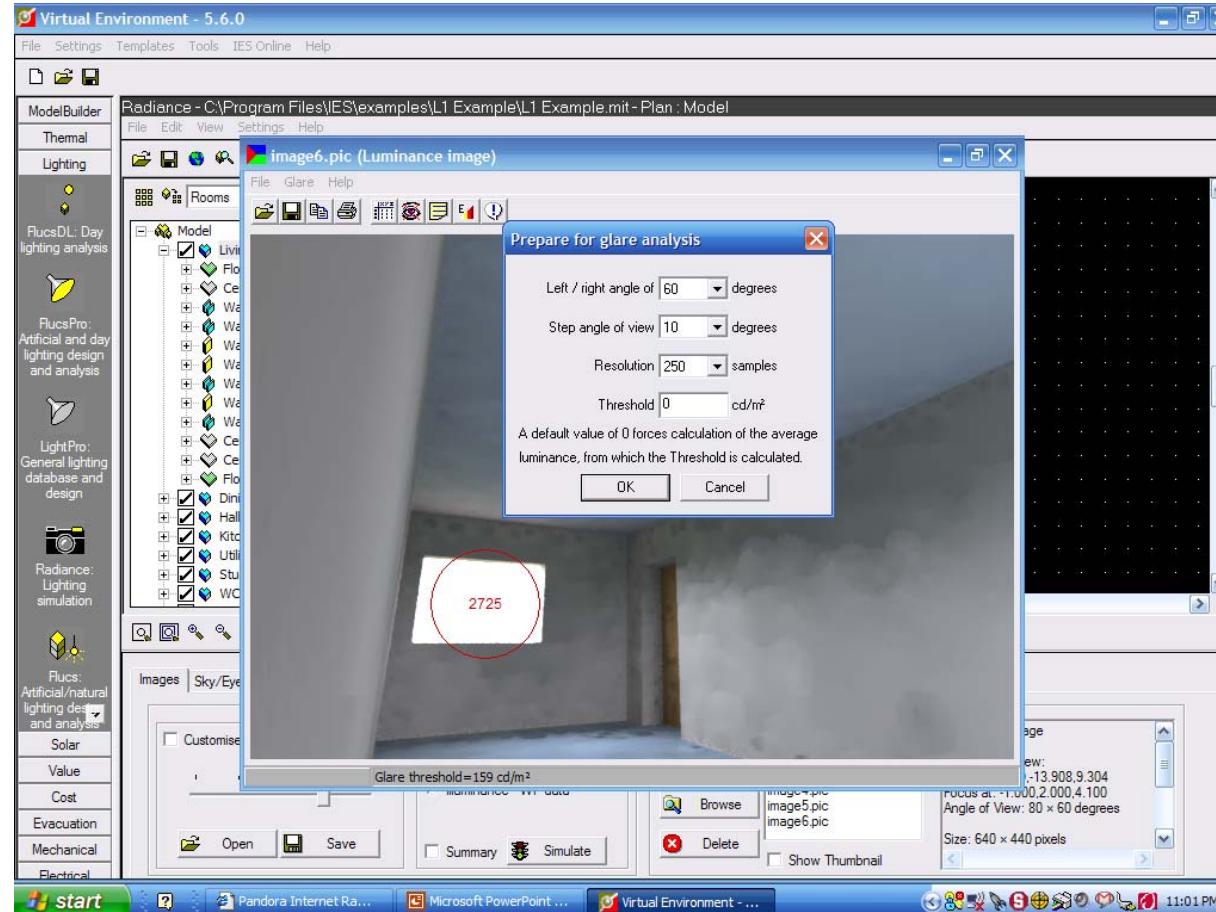


IES- Illuminance Contours



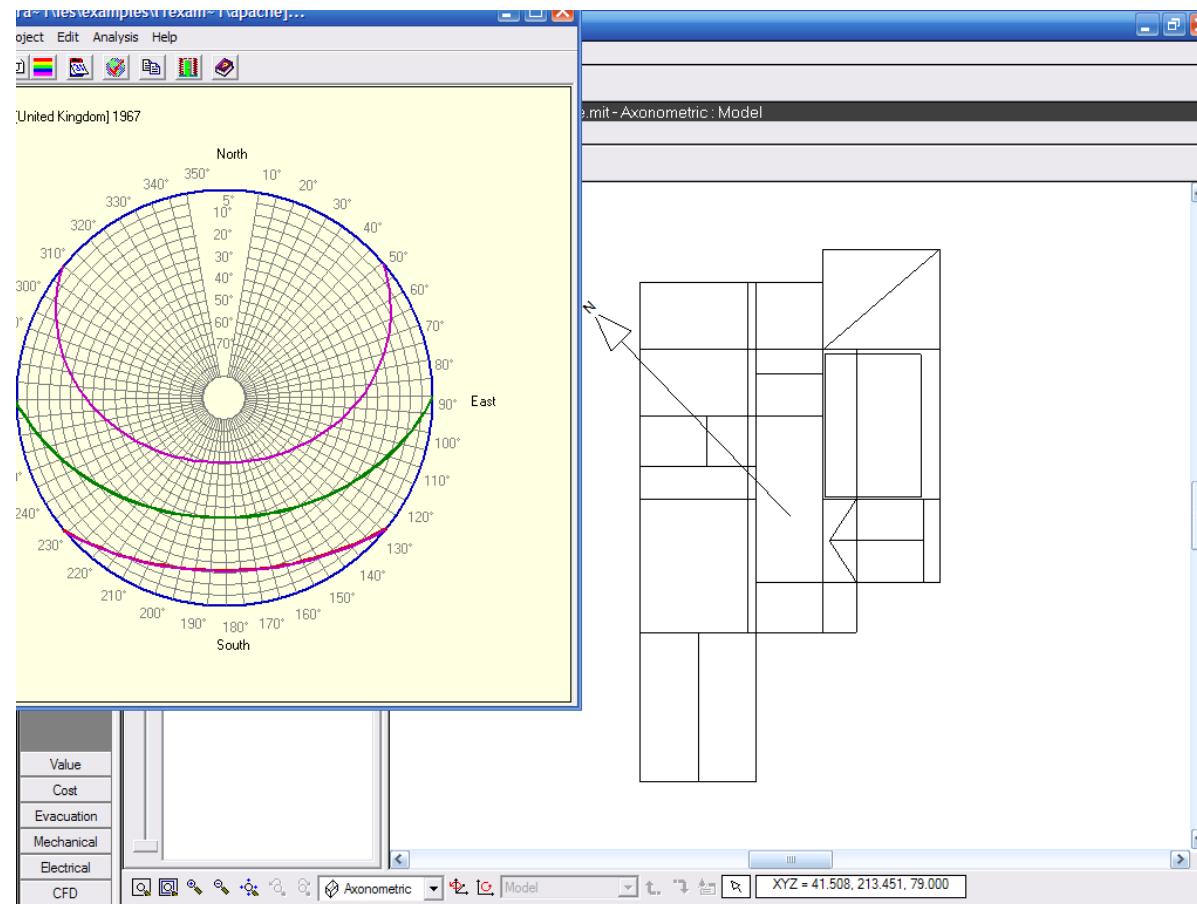


IES- Glare Analysis



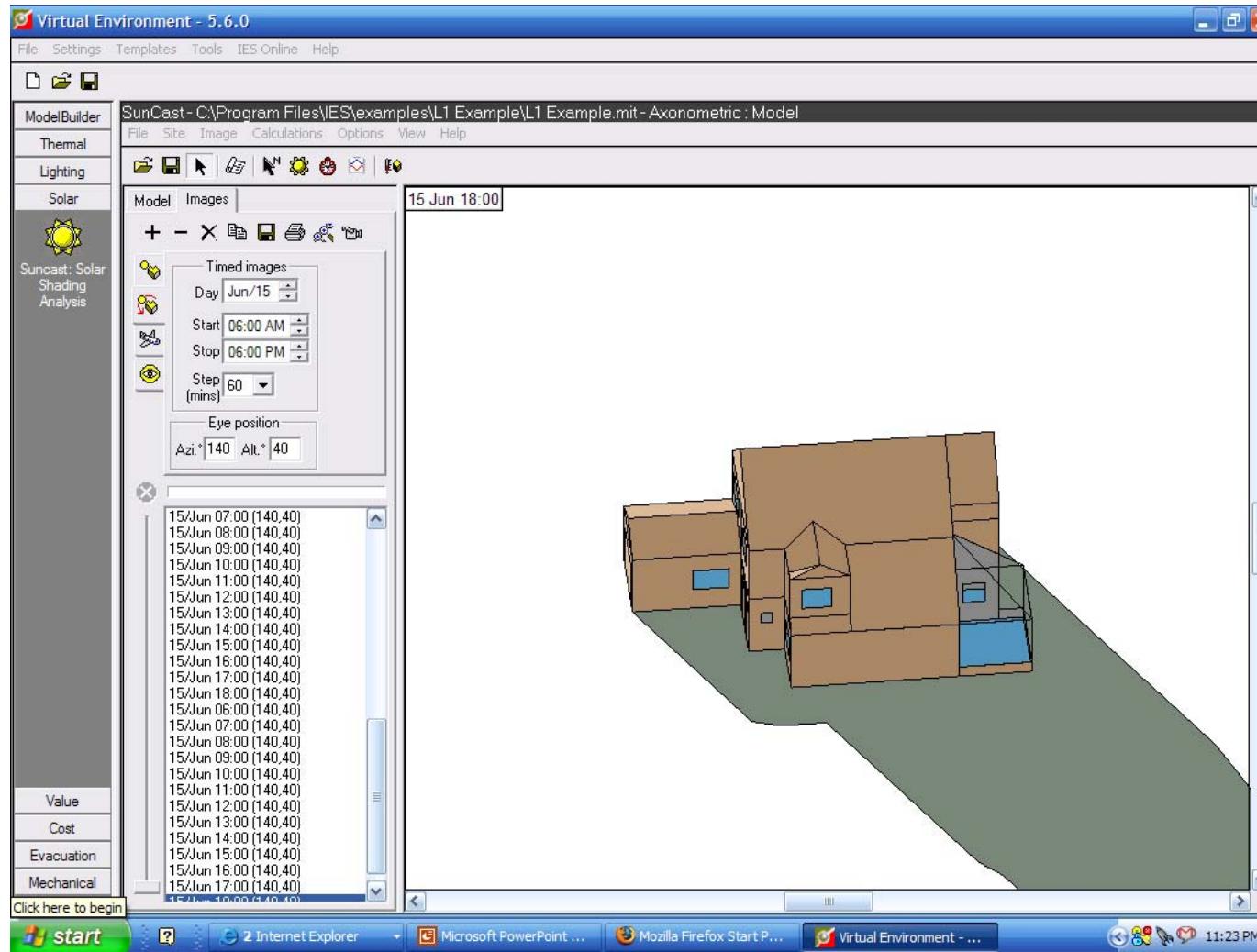


IES- Sun Path Diagrams





IES- Shading Study





Questions?